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Fire Growth Analysis of the Fire of March 20, 1990, Pulaski Building, 20 Massachusetts Avenue, N.W., Washington, DC

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United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

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1. ABSTRACT

An analysis of an office building fire was made using fire modeling techniques. The data to conduct the analysis was obtained through on-site inspection and interviews. The analysis describes a rapid fire developing in easily ignited boxing materials that flashed over in about six minutes from flame initiation, causing failure of the ceiling system, venting of fire products in the plenum system above the ceiling, and rapid filling of the entire flow area with smoke. The report suggests a likely source of ignition and provides analysis of the impact that several fire protection systems would have had were they present at the time of this fire.

2. SCOPE

This report addresses the growth and spread of the fire of March 23, 1990, in suite 5127 of the Pulaski Building, 20 Massachusetts Ave. N.W. Washington, D.C. This reconstruction analysis was conducted at the request of the Safety & Occupational Health Office, Corps of Engineers (COE), U.S. Department of the Army. The suite of rooms involved in the fire was occupied by the Army Battlefield Monuments Commission (ABMC). Figure 1 locates the ABMC suite on the plan of the 5th floor of this building.

3. PURPOSE

The overall purpose of this report is to assist the COE in obtaining an accurate understanding of the events of the fire as an input to their decision making. An additional intent is to demonstrate the value of the application of a scientifically sound fire protection engineering tool in fire safety analysis. The specific purpose of the reconstruction analysis contained in this report is to identify the course of events in terms of what was or was not physically possible when considered in light of the laws of science applicable to fire. To do this a two step process was used:

1. Those specific events and conditions reasonably identified or derived from the physical evidence at the fire site, the recollections of witnesses, and the records of the District of Columbia Fire Department were established.

2. Application of the applicable laws of science was then used to estimate the rate of fire growth and resulting environmental situation that most nearly fit the established events and conditions. Fire modeling techniques were used to implement this phase.

This led to the establishment of a most likely course of events as is described in the next section of this report.¹ This is followed by several sections detailing the technical aspects of the analysis and a final section providing the conclusions drawn.

4. BRIEF ACCOUNT OF THE FIRE

At approximately 11:24 to 11:25 a.m., a ABMC staff member noted smoke emitting from the open door of the unoccupied Audio/Visual (A/V) room. (See Figure 2 for the layout of the ABMC suite and the normal workstations of the ABMC staff.) He called out a warning.

¹ This approach to the application of fire science and the use of fire modeling as a tool in fire incident reconstruction has emerged during recent years as an important tool in fire incident investigation. Two examples of the application of these techniques are contained in the reports:

"An Engineering Analysis of the Early Stages of Fire Development - The Fire at the Dupont Plaza Hotel and Casino - December 31, 1986" Report NBSIR 87-3560, National Institute of Standards and Technology, Gaithersburg, MD, 1987.

"An Engineering View of the Fire of May 4, 1988 in the First Interstate Bank Building, Los Angeles, California" Report NISTIR 89-4061, National Institute of Standards and Technology, Gaithersburg, MD, 1989

Others responded and quickly identified the Conference Room adjacent to the A/V room as the room containing the fire. The Conference Room at that time was being used for the storage of ABMC publications and other materials. The likely, but not certain, cause of the fire was the shorting and subsequent flaming of the cord for the lamp on the Conference Room podium, resulting in the ignition of corrugated boxes containing cardboard mailing tubes.

As is characteristic of fires involving boxes of corrugated paper board construction, the fire developed at a very rapid rate. By about 11:26 a.m., the fire in the Conference Room flashed over². With this occurrence, large quantities of hot black smoke flowed into the rest of the suite. It is likely that the initial post flashover flow of smoke contained potentially lethal concentrations of carbon monoxide. Very soon after flashover, however, the suspended ceiling in the Conference Room started to fail, as this ceiling opened up, the smoke and heat vented into the open plenum space above the ceiling. This changed the nature of the fire from one confined to the suite to one spreading high temperature

²Flashover is a phenomena that occurs in most major building fires. In the initial (pre-flashover) stages, fire development is controlled entirely by the availability of combustible materials, the ease of fire spread and subsequent burning rate of the involved fuel. As the fire develops, however, the hot smoke and fire gasses accumulating at the ceiling, heating all of the yet un-ignited materials in the room. The hot ceiling gases also radiate energy onto the burning fuel causing it to burn faster. This increased burning rate often results in a throttling of the available air supply, causing some of the fuel gases released by the combustible material to collect, unburned, in the smoke layer. The smoke normally blackens at that time. When this combination of events reaches a temperature of about 1000 to 1100 degrees F (550 to 600 degrees C) the radiant heat from the hot gas layer will quickly ignite all of the exposed combustible material. Frequently any combustible gases accumulated in the smoke will find air and burn out at about the same time. When this rapid ignition of exposed combustible material and/or combustible gases in the smoke layer occurs, the fire often violently erupts from the room of origin spouting flame, hot fuel laden gases, and toxic smoke into adjacent spaces. This transition is called flashover.

combustion products through the plenum space and from that space to other portions of the fifth floor. To some extent, smoke also spread to other floors (though the make-up air shafts for the HVAC fans).

The ceiling failure slowed the deterioration of conditions in the ABMC suite, possibly avoiding serious harm to the last person(s) to leave the suite. The failure of the ceiling exposed the wiring of the fire alarm system to direct flame impact, causing it to fail. The fire alarm system failed just moments after a fire alarm box had been pulled by evacuees from the ABMC and adjacent suites. Soon thereafter, portions of the building lighting circuit also failed. The flame entered the plenum space, thus limiting actual burning to the contents of the Conference Room and adjacent spaces. As the flame and other fire effects vented into the plenum, the lighting fixtures and other utilities in the plenum were subjected to flame (nearest the fire source) and hot gases.

From this point on, the fire effects spread through the plenum and entered the office spaces under the ceiling through the ceiling vents and other openings and leakage cracks in the ceiling system. Following this route, the fire involved the entire floor space, filling it with smoke from the ceiling void down; the areas nearest the source being the hottest. Small quantities of polychlorinated biphenyls (PCB) were released from condensers in the florescent lamp ballasts in ceiling fixtures located close enough to the actual burn area to receive sufficient heat to rupture the condenser elements. This contaminated smoke left

heavy deposits over most of the 5th floor and lesser but significant deposits on the 4th and 6th floors.

As the fire progressed, the venting of the flame into the plenum void protected most of the other spaces in and near the ABMC suite from ignition. The lighter fuel elements in the Conference Room (e.g., the mailing tube boxes and other loosely packed materials and exposed surfaces of corrugated boxes) determined the initial rapid development to flashover but were quickly consumed. The exact duration of such burning is impossible to establish but was probably over in the range of about five minutes following flashover. Under normal post flashover conditions, it would be expected that the intense conditions within the room would have continued the fire at nearly the same intensity. In this fire, however, there were two mitigating circumstances that are felt to have resulted in a fire that after having established itself, died without consuming more than a small portion of the total fuel present in the Conference Room. First the failure of the ceiling vented a significant portion of the flame into the plenum space. This raised the flame from the remaining combustibles into the plenum space. The shielding provided by the remaining portions of the ceiling greatly reduced the amount of energy feedback to the burning combustibles. Also, as the fire continued, it progressively reduced the oxygen available for combustion. As the oxygen depleted smoke layer descended to the level of the fuel, it depressed the burning rate. As a result, about 80 to 90 percent of the fuel content of the materials in the Conference Room remained unburned after the fire. The fire was essentially out when the responding firefighters reached the area of the ABMC space. The time of the arrival of the first

firefighter at the ABMC space cannot be exactly established but is estimated at between 11:35 and 11:40.

Fortunately, no lives were lost; however, significant contents and partitioning damage occurred through approximately 2000 square feet of the 5th floor with contaminated smoke deposits requiring temporary abandonment and extensive decontamination of the entire 4th, 5th, and 6th floors.

5. PERTINENT DETAILS

5.1 Building Structure

The building is of flat slab reinforced concrete construction. There is a suspended gypsum panel ceiling in an exposed steel grid system. The ceiling system is not fire rated.

5.2 Partitions/Layout

All partitions, except those for shafts, restrooms, and similar special purpose spaces, are terminated at the ceiling. A main loop corridor with a cross connection at the elevator lobby is formed with ceiling-high, gypsum-board-on-steel-stud partitions. This results in an undivided space about 18 inches deep above the ceiling extending over most of the floor area. This space is used as a return air plenum.

The ABMC occupied a suite of approximately 2500 square feet in the south west corner of the 5th floor. The suite ran in an east-west direction with a door near each end. Each of these doors opened from the building circulation corridor into a general circulation space. There was an internal corridor running in the east-west direction. Offices were located on the south (exterior) side with a conference room, a related A/V room, and several other service rooms on the north (interior) side.

5.3 Lighting and Air Conditioning

Lighting throughout the building is provided by four tube fluorescent fixtures mounted in the ceiling grid. Each light fixture has two Underwriters Laboratories (UL) labeled ballasts of the thermally protected type. In many of the light fixtures, two of the four fluorescent tubes have been removed.

The building lighting fixtures also serve as air supply and air return fixtures. Each 4th to 5th light fixture is connected to an air supply duct fed from a fan room serving one half the floor. There are two fan rooms on each floor. The vent openings in the other fixtures provide the air transfer paths from the occupied portion of the building beneath the ceiling to the return air plenum space above it. Each floor is an independent air handling system. There is no designed passage of air from floor to floor.

There are no return air ducts in the general air conditioning system in this building. The arrangement of the air handling fans is shown in Figure 3. Air is drawn into the each fan from the air in the fan room. The fan room partitions terminate at the ceiling, providing free flow of return air from the ceiling plenum to the fan room.

Return air is drawn by the fans from the occupied space through those lighting fixtures that are not connected to supply ducts, through the plenum space, into the fan room. The air is then pulled, by the fan suction, into the fan feed opening of one of the fans in the fan room and recirculated (after conditioning) through those lighting fixtures that are connected to supply ducts. Make-up air is also drawn into the fan room by fan suction from a vertical shaft connected to the outside. In addition to the designed openings between the make up air shafts and the fan rooms, additional openings have been created by breaking out portions of the concrete block separation between the shaft and the fan room. Such an additional opening was found in each fan room inspected during the investigation. There are no fire or smoke dampers in the system.

5.4 Suite 5127. ABMC

During the several weeks prior to the fire, the ABMC was required to remove its storage of bulk quantities of pamphlets, lithographs, and other material from a space in the basement of the building. The material was relocated to suite 5127. Also, in preparation for expected laying of carpet in the east half of the suite, the supplies normally stored in the

storage area and the A/V room were relocated to space in the west half of the suite. In general, every available space in the west portion of the suite was used to accommodate these materials. The Conference Room received the bulk of the material. Figure 4 is a plan view of the Conference Room showing the arrangement of the storage in it. Based on the data supplied and the average weight of paper, there was about 10,000 pounds of combustible material in the Conference Room. Most of the combustible material consisted of publications and lithographic photos either tied in bundles or contained in corrugated cardboard boxes. Most important to the principal suspected fire scenario, corrugated board cartons containing cardboard mailing tubes were stacked to a height of about 5 feet in the north east portion of the room.

As of this date, no plans, photos, or clear recollections of the arrangement of the lighting fixtures in the Conference Room have been obtained.

There was a plastic rear projection screen mounted in the wall between the A/V room and the Conference Room. It is understood that this screen was covered by a draw curtain of unidentified material. The equipment for making presentations was located in the A/V room and viewed from the Conference Room.

The Conference Room contained a podium (See Figure 5.) This podium had controls to remotely operate a slide projector located in the A/V room. It also had a podium light. The light is believed to have been a small 110 volt low wattage lamp with current supplied

by a simple lamp cord. The lamp cord and the control wires passed through a small diameter (estimated at about 1 inch diameter) hole cut in the partition separating the A/V room from the Conference Room. It is understood that this arrangement was made some years ago and at the time it was done, the portion of the cord in the pass through hole had been wrapped with friction tape.

During the re-arrangement of the Conference Room to receive the material moved from other locations, this podium was moved without disconnection of the cord arrangement. The podium was moved a few feet from a position near the north east corner to a location on the east wall near the north edge of the rear projection screen.

It is not known whether the movement of this podium along with the arrangement of the storage placed any stress on the lamp cord or otherwise caused it to be pinched or drawn against a sharp edge. Any remains that existed were disposed of with the fire debris prior to the start of this analysis.

6. ANALYSIS APPROACH

The Center for Fire Research was called in to this investigation several weeks after the incident. When the CFR representatives arrived, the contents of the Conference Room and most of the contents of the A/V room had been removed and were either unavailable or

unidentifiable in a trash dumpster. Shoring had been installed throughout these rooms. The remainder of the suite was close to the condition found at the end of the fire. Several video and photographs were available that showed some views of the Conference Room area prior to removal of the damaged contents. The information available from these, while helpful, was limited.

The author, jointly with representatives of the Corps of Engineers, interviewed ABMC staff members that were involved in the fire or events related to it. Data was obtained from the District of Columbia Fire Department and from Mr. Joseph O'Hagan, the first Federal fire protection professional to investigate the site after the fire.

The information obtained gave a generally sufficient outline of the sequence of conditions faced by the ABMC staff, the response of the building system (fire alarm and electric lighting), the building arrangement, and the fuel load conditions in the Conference Room.

The physical arrangements pertinent to the fire are graphically depicted in figures 1 through 5. The analytical results of the engineering calculations are plotted in figures 6 through 12 and graphically depicted at one minute intervals in figures 13, 15, 17, 19, 21, and 23. The actual variables and results of the principal calculations involved are contained in appendices A through D. The principle analysis tools used were the programs and procedures included

in FPETOOL.³ Figures 14, 16, 18, 20, 22, and 24 track the activities of the ABMC staff up to the time the ABMC suite was evacuated (approximately 11:27 a.m.) Data for these figures was obtained from interviews of the staff members involved. Figure 25 combines important events of fire development, staff, and fire department activities into a single time line.

7. ASSUMPTIONS

In any fire reconstruction analysis, it is necessary to make rational assumptions to fill information gaps and resolve apparent inconsistencies in the data and testimony available. While the basic character of this fire was evident, a number of assumptions were required. Each assumption necessarily impacts on the degree of confidence in the results. The most significant assumptions include:

1. The assumed initial fuel package was cartons of mailing tubes in the north east corner of the Conference Room.

The only persons to actually see conditions in the Conference Room were persons B (a senior secretary) and E (a senior military officer.) While their recollections are similar, neither recalls seeing the other in the vicinity of the Conference Room. While both must

³FPETOOL is a computerized collection of convenient fire protection engineering equations and models designed for fire hazard and fire investigation analysis. The computer program FPETOOL is available through the Center for Fire Research Computer Bulletin Board and is documented in the NIST report NISTIR 4380 "FPETOOL - Fire Protection Engineering Tools for Hazard Estimation"

have been near the door to the Conference Room within a time period of less than one minute, there is no clear way to determine which observed the fire first. More important is the fact that both of these individuals saw flame at the ceiling, while the most logical scenario for this fire places the base of the fire near the floor.

Person E stepped from his office almost directly across the internal ABMC corridor from the open west door of the Conference Room and saw "ropes" of flame extending downward in a partially separated sheet from the ceiling. The flame seemed to stop short of the table top and to be about 1 to 2 feet wide. Person E placed the flames he observed near the center line of the Conference Room in the east quarter of the room but not against the east wall. There was some initial consideration that the source of this flame might have been from an overheated fluorescent lamp ballast and person E might have seen the initiation of the fire. However, person E did not become involved in the fire sequence until after person G and several others had observed smoke issuing from the A/V room. Such smoke build-up would have necessitated a fire of larger size than possible from the total combustible fuel in a light ballast. More likely, person E saw the burning of the plastic lens for a fluorescent fixture, hanging from one end and on fire. The level of confidence in this possibility could be better analyzed if the actual arrangement of the ceiling lighting fixtures could be established. Even so, for this analysis, it is assumed that person E saw a flaming lens. The specific of what was burning is not individually important. However, it is concluded that at the time described by person E, the fire was in a sufficiently advanced stage of burning for

flame extension to ignite a fuel at the ceiling.⁴ Figure 6 is a graph of the estimated flame extension against time.

Person B also reported seeing flame flowing downward from the ceiling. She did not actually reach the door to the Conference Room (See figure 20). While she stated that she saw the east wall of the Conference Room, the viewing angle from the position she recalled she took would reveal only the north wall (the approximate location of her viewing position is indicated on figure 20 by the tip of the arrow extending from her workstation towards the Conference room.) Even if she had approached closer to the Conference Room, only the north wall would be visible unless she had actually stood at the door of the Conference Room. She was firm in her recollection that she did not actually go to the Conference Room door. On this basis, this analysis assumes that she saw flame extension from the actual fire source and the downward movement of a flame vortex extending from the source along the junction of the ceiling and the wall.

⁴When the results of the investigation were discussed with ABMC staff members, person E felt that the scenario considered as most likely (i.e., the one presented in this report) was at odds with his observations. The scenario estimates the person E probably first saw the fire at about 11:24 to 11:25 a.m. This would place the fire size as between 1 and 2 megawatts with flame extension estimated at 9 to 11 feet. Such would produce a flame sufficient to ignite the fluorescent fixture lens and to that extent fits person E's observation. Person E, however, believes that he had a clear view and the only flame he saw was extending downward from the ceiling. Such a fire would be expected to be in the range of 100 to 200 kilowatts (i.e., 0.1 to 0.2 megawatts). When person E looked again (estimated as within one minute of his first observation), the smoke had changed to a black obscuring condition and was highly turbulent (described as boiling by person E). The fire growth rate necessary to raise the conditions from a localized fire as recalled by person E at his first look to the violent conditions observed at his (about 1 minute) later would require a growth rate beyond that expected for the types of combustible materials present. The assumption of a 1 to 2-megawatt fire at the time person E first observed the flames from the ceiling requires the corollary assumption that the actual combustion at that time was significantly more than that indicated by those flames observed by person E.

2. The cause of the failure of the fire alarm system was flame impingement on a section of fire alarm cable in the ceiling void over the Conference Room.

The structural fire resistance in this building is provided by the reinforced concrete construction. The suspended ceiling plays no part in this function. The ceiling system is supported by an exposed metal grid and does not have a specific fire resistance. The portion of the ceiling system in and around the Conference Room failed during the fire. It is believed that this occurred soon after the Conference Room flashed over. It is believed that the first significant failure occurred at about 11:27 a.m. At that time, the fire alarm was heard but, as reported by ABMC staff members, sounded for only a few seconds. A fire alarm circuit was located in the partition between the Conference Room and the building circulating corridor. A similar installation was examined on the 7th floor. At that location, the alarm circuit was partially in conduit and partially exposed. The exposed portion being above the ceiling line. For this analysis it is assumed that the ceiling in the Conference Room failed at approximately 11:27 a.m. and that the failure was extensive. This is assumed to have allowed flame impingement on the fire alarm wiring. This conclusion is important in the analysis. The ceiling failure had a major impact on fire development as discussed in the preceding section on the story of the fire.

3. The doors to the ABMC suite were closed at the start of the fire but opened by escaping staff members about 11:26 a.m.

The opening of the ABMC suite doors by the staff as they evacuated had an effect on the smoke accumulation within the suite. The exact time can only be estimated. While it is not likely that both were opened at the same time, this analysis for lack of more concise data assumes that both doors were opened at 11:26 a.m. The assumption that the doors were first closed and then opened impacts the rate of smoke filling of the ABMC suite.

4. The initial fire growth was rapid and exponential in rate of increasing intensity.

The use of the procedures in FPETOOL for analysis of this fire requires an estimate of the rate of energy release produced by the fire source up to the time that flashover occurs. Every different ignition of any fuel produces at least a slightly different burning history. Experience has shown, however, that a reasonable approximation can be made by assuming that in the initial stage the burning rate increases exponentially with the exponent increasing with time. After the fire reaches a more steady rate of burning per unit surface area, the rate can be estimated as increasing with the square of time. FPETOOL includes routines for making such estimates. There is a reasonable database on the burning rates of materials in corrugated containers. The burning rate is consistently fast. Several variations were tried. That which FPETOOL indicated as producing fire conditions most nearly consistent with the conditions reported by the witness was used. The specific equations and resulting rate of

heat release history used are shown in Figure 7. The rates used are approximately those most expected from corrugated boxes⁵

5. The initial stages of burning were clean with an excess of available combustion air. As the fire developed, this changed to a smokey fuel rich fire.

The fact that persons B and E could see details of the flame briefly before flashover is considered indicative of very clean burning up to a point close to flashover. This is felt to be a reasonable assumption since the prime fuel consisted of paper products and there was adequate air for complete combustion in this stage of burning. As the fire approached flashover, the rate of fuel gas driven from the combustible material in the room started to exceed the amount of combustion supportable by air drawn in through the Conference Room door. With this, the efficiency of combustion started to reduce, resulting in a rapid darkening of the smoke.

8. CALCULATIONS

FPETOOL contains an integrated calculating procedure for estimating conditions in a room on fire. This procedure is titled FIRE SIMULATOR. FIRE SIMULATOR estimates the environmental conditions, temperature, depth of smoke, thickness of smoke, carbon

⁵ A listing of the rates of heat release to be expected from various fuels, including corrugated boxes is contained in NFPA Standard 204M, Guide for Smoke and Heat Venting published by the National Fire Protection Association.

monoxide in the smoke, and other environmental changes caused by a fire in the room being evaluated. It also estimates the amount of energy vented through openings in the room.

The calculations were divided into three stages individually covering: (1) the development of conditions in the Conference Room; (2) conditions through the rest of the ABMC suite; and (3) conditions throughout the 5th floor. Until the ceiling failed at about 11:27, the conditions in the ABMC suite resulted from smoke, gases, and vaporized fuel products emitted from the open door of the Conference Room. During this same period, a limited amount of these same products vented into the plenum space filling that void. Once the void was filled, smoke vented through light fixtures into spaces outside the ABMC suite. At the time of the Conference Room ceiling failure, the smoke had descended to about one to two feet below the ceiling line. When the ceiling failed, the total force of the fire was directed into the plenum space and the smoke level in the Conference Room and the ABMC suite started to rise. Shortly after that, the smoke vented down through the ceiling vents (vents in light fixtures and other openings) and reached the level of the smoke in the Conference Room and the ABMC suite. From this point on the smoke level is estimated as being at the same depth across the entire 5th floor.

Initially, FIRE SIMULATOR was used to appraise the development of conditions in the Conference Room. A number of runs were made in order to estimate the clock time of fire initiation. This was done by assuming that flashover occurred at approximately 11:26 a.m. While this is an arbitrary assumption, it fits closely with the recollections of the persons

present and the timing of the alarm received by the fire department: FIRE SIMULATOR estimates that given the condition of the room and a fire releasing an energy at the rate plotted in Figure 7, that flashover would occur at about 268 seconds into the fire. This would place the moment of open flaming ignition at approximately 11:21:30 a.m. Such an estimate is, of course, overly precise as the energy release rate of the fire may have taken a somewhat different course than that predicted by Figure 7. It is reasonable, however, to assume that the first appearance of flame was in that time period. It is recognized that 11:21:30 a.m. is uncertain. It is, however, used throughout this analysis as the moment of flame initiation.

In addition, FIRE SIMULATOR was instructed to halt approximately one minute after flashover (330 seconds) in the simulation (i.e., 11:27 a.m). At that time, the program was instructed to simulate failure of the entire ceiling system. While it is known that grid type ceiling systems can fail quite suddenly, it is probable that it was not instantaneous as modeled. The instant total failure simulation was used, however, for lack of a better approximation.

The combination of energy and potential fuel in the vented gases from the door were used as the input fire to make initial estimates of the change and conditions throughout the portions of the ABMC suite outside of the Conference Room.

After ceiling failure, it was assumed that all the portions of the entire floor open to the plenum became affected by the fire in the Conference Room and another execution of FIRE SIMULATOR was based on the entire floor area filling through that route. In this appraisal, extra perimeter wall area was added to account for the heat absorption capabilities of the subdividing partitions. Based on an approximation of the partitioning shown on the floor plan, the actual building perimeter was increased by a factor of three.

Appendices A, B, and C are detailed printouts from these three runs of FIRE SIMULATOR as follows:

1. Appendix A provides the data for the estimation of conditions in the Conference Room from the start of the fire until approximately 11:28. After that time, it is believed that general smoke filling of the entire fifth floor encompassed the conditions in the Conference Room and the entire floor is best modeled as a single space.
2. Appendix B covers the average development of conditions estimated for the suite. This is also terminated at approximately 11:28 when conditions were believed to have stabilized and the further development of fire in the suite became simply another part of the general condition throughout the floor.

3. Appendix C provides the printout of the estimation for the total floor area. After the ceiling failure, the fire spread heat and smoke into the void and forced heated smoke through the ceiling vents into the corridors and other offices throughout the floor. To estimate the impact of this, FPETOOL was used to model the entire floor as a single area of fire impact.

Figures 8 through 12 provide graphic representation of the estimated change in environmental conditions. These graphs cover rise in temperature, estimated depth of smoke, oxygen in the smoke, carbon monoxide increases in the smoke, and vision distance through the smoke.

Figures 13 through 24 are an attempt to provide a pictorial time-line sequence showing the movement of people in contrast to the development of fire from the time of fire outbreak until the completion of evacuation of the ABMC suite. Figure 25 presents the key data and information in a single time-line.

9. ALTERNATIVE PROTECTION METHODS

An analysis of the likely course of events had alternative protection mechanisms been available was made. The analysis in each case is based on the presence of the mass of combustible material in the Conference Room producing a rate of heat release such as

described in Figure 7. The impact of smoke detectors, standard or quick response sprinklers, and that of fire resistive partitions were considered.

1. Smoke Detectors - FIRE SIMULATOR indicates that a smoke detector located near the center of the Conference Room would have detected the fire at about 11:23 a.m., 1 1/2 minutes after initiation. This would be about one minute before smoke was seen by members of the staff. The fire at that time was small and could have been attacked with a fire extinguisher. The probability of successful attack, however, is felt to be low since it would have been necessary for the staff to have recognized the alarm, discovered the point of origin, found a fire extinguisher, and correctly used it. The estimated fire growth rate at this time was such that in less than one minute following such smoke detection, the fire would be beyond attack by fire extinguisher. If not extinguished by that time, it must be expected that the fire would have proceeded in the course that it took regardless of the early detection.
2. Sprinkler Protection - The probable response of both quick response and standard sprinklers as might have been installed in the Conference Room were evaluated. FIRE SIMULATOR predicts the activation of a typical quick response sprinkler at approximately 134 seconds after initiation (or about 11:24 a.m.). This would be in a general vicinity of the time at which the staff first became aware of the fire. In addition, FIRE SIMULATOR estimates that a standard sprinkler head would have operated about one minute later at approximately 169 seconds. The normal sprinkler

head currently used in sprinkler protected office occupancies is the standard head. This head would probably have operated at about the time Person E first observed the fire. The type of fire involved is one expected to be controlled by a normal sprinkler system in good operating order. Because of the shielding of the large conference table, it is quite possible that some burning would have continued until arrival of the fire department for final extinguishment. It is not expected, however, that any failures of ceilings, partitions, or other heat damage would have occurred outside the room of origin. Smoke would have spread through the suite and possibly been picked up by the HVAC system and distributed through the rest of the building. While such smoke could be quite dark, it would be cool, high in oxygen, and low in noxious or corrosive materials. The smoke and fire gases would not have been hot enough to rupture the PCB containing condenser in the light ballasts. The printout of the FIRE SIMULATOR runs used to form these conclusions is contained in Appendix D.

3. Fire Resistive Partitions - Many newer office buildings subdivide each suite from the corridor and from any other suite by fire resistive partitions extending from floor to slab. Had such been present, the fire would have been confined to the ABMC space and the ceiling spaces above it. Damage in that space would have been at least as extensive as that which actually occurred. Since the fire would have vented into a much smaller plenum, it is quite possible that fire damage would have extended over wider range of the ABMC space. At least as many ballasts would probably have

been involved and the extent of spread of contaminated smoke would have then depended upon the presence or absence and operation or failure of fire and smoke dampers in the distribution system.

10. CONCLUSIONS

The fire events and conditions predicted using the calculation procedures in FPETOOL give a rational explanation of how the fire developed and what factors determined its course.

The most likely source of ignition is an electrical short in the lamp cord for the podium lamp, causing this to flame and ignite the adjacent corrugated boxes. The fire developed rapidly due to the characteristic rapid burning rate of the initial fuel (corrugated boxes). The occupants had no chance to alter the sequence of events given the conditions at the time of discovery. Collections of combustible materials in the quantities that existed in the Conference Room always present major hazardous potentials. Established fire safety criteria as found in building codes and Federal agency criteria⁶ would require that such combustible concentrations be enclosed in fire resistive rooms or protected by automatic sprinklers.

⁶ Most Federal agencies use the Life Safety Code published by the National Fire Protection Association as part of their criteria. Section 27-3.2.1 of the 1988 edition of that code addresses hazardous areas in existing office buildings. That paragraph requires either sprinkler protection or a fire resistive separation for hazardous areas including those used for general storage.

FIGURE 1. 5TH FLOOR, 20 MASSACHUSETTS AVE. NW
WASHINGTON D.C.

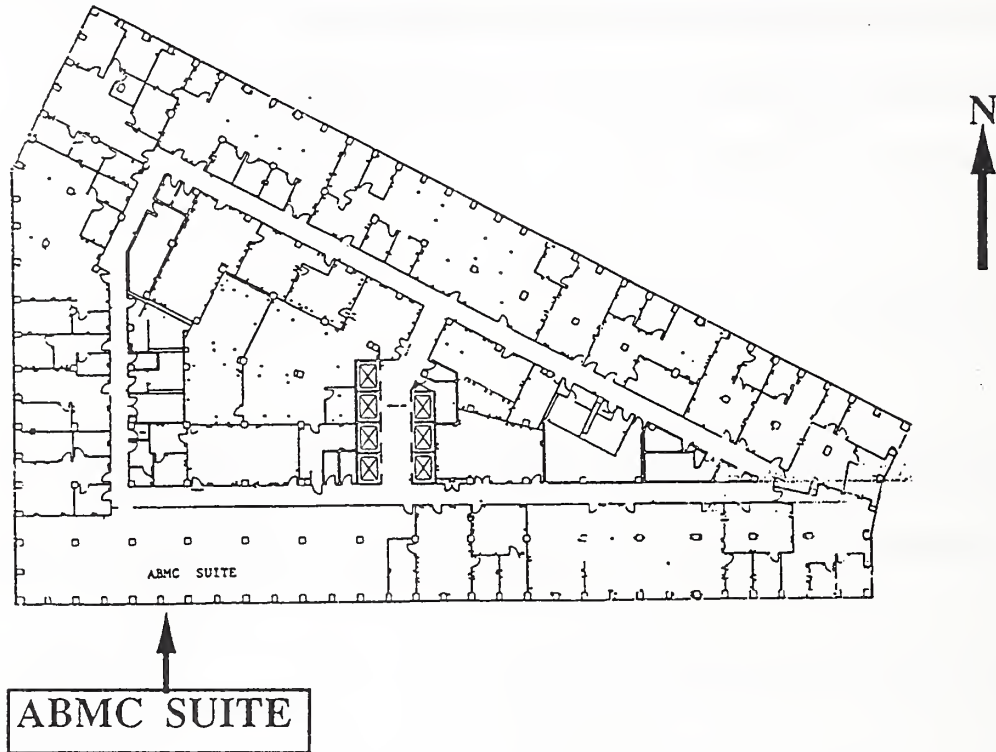


FIGURE 2. SUITE 5127 - ARMY BATTLEFIELD MONUMENTS COMMISSION

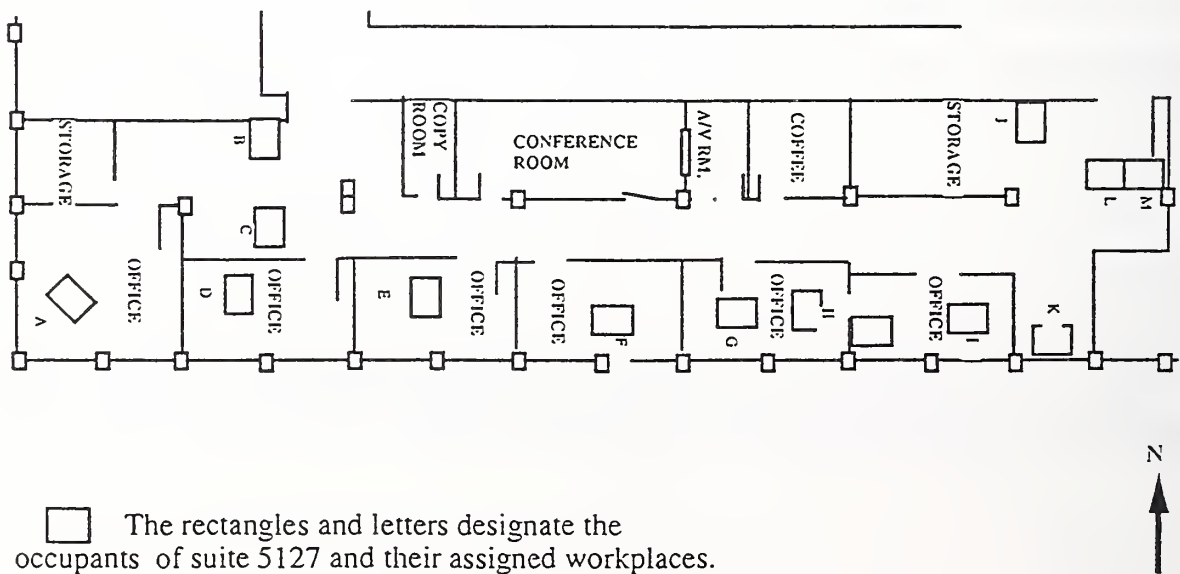
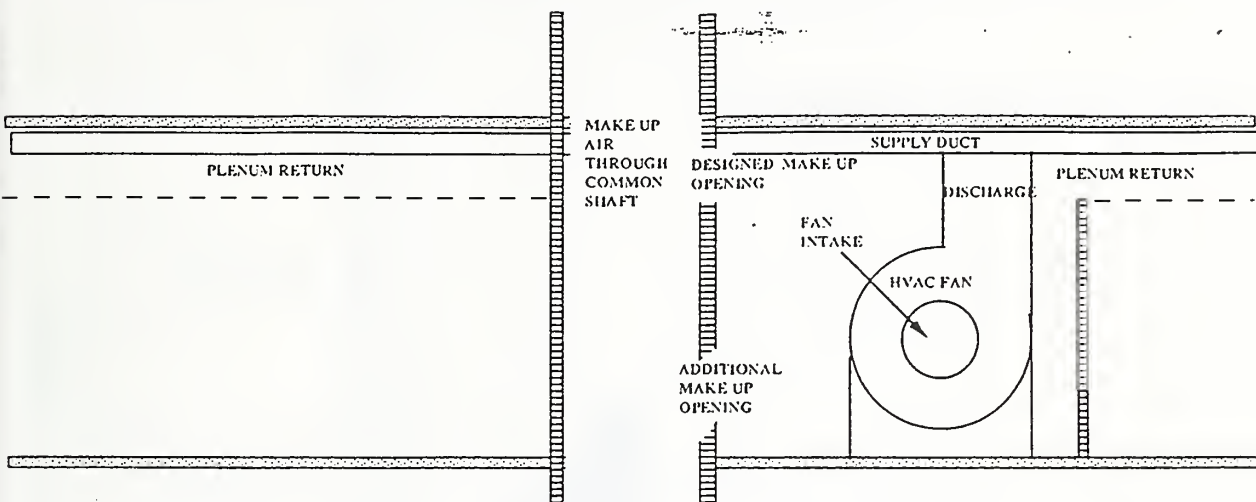


FIGURE 3 FAN ROOM ELEVATION (TYPICAL)



EACH FLOOR IS SERVED BY TWO FAN ROOMS. THE FANS IN EACH FAN ROOM INTAKE AIR FROM THE FAN ROOM ENVIRONMENT AND DISCHARGE IT INTO THE SUPPLY DUCT SYSTEM. THE AIR IS DISTRIBUTED BY THE DUCT TO SUPPLY AIR AROUND CEILING LIGHT FIXTURES. RETURN AIR IS RETRIEVED THROUGH OTHER LIGHT FIXTURES (AND SOME RETURN AIR GRILLS) IN THE CEILING. THE RETURN AIR PASSES THROUGH THE CEILING VOID (PLENUM) AND IS DRAWN INTO THE FAN ROOM THROUGH OPENINGS BETWEEN THE FAN ROOM AND THE PLENUM. MAKE UP AIR IS DRAWN BY THE SUCTION OF THE FAN FROM A SHAFT THAT SERVES THE FAN ROOMS ON ALL FLOORS. IN MOST FAN ROOMS THE SHAFT WALL HAS BEEN BROKEN OPEN IN AN EFFORT TO INCREASE THE PORTION OF MAKE UP AIR.

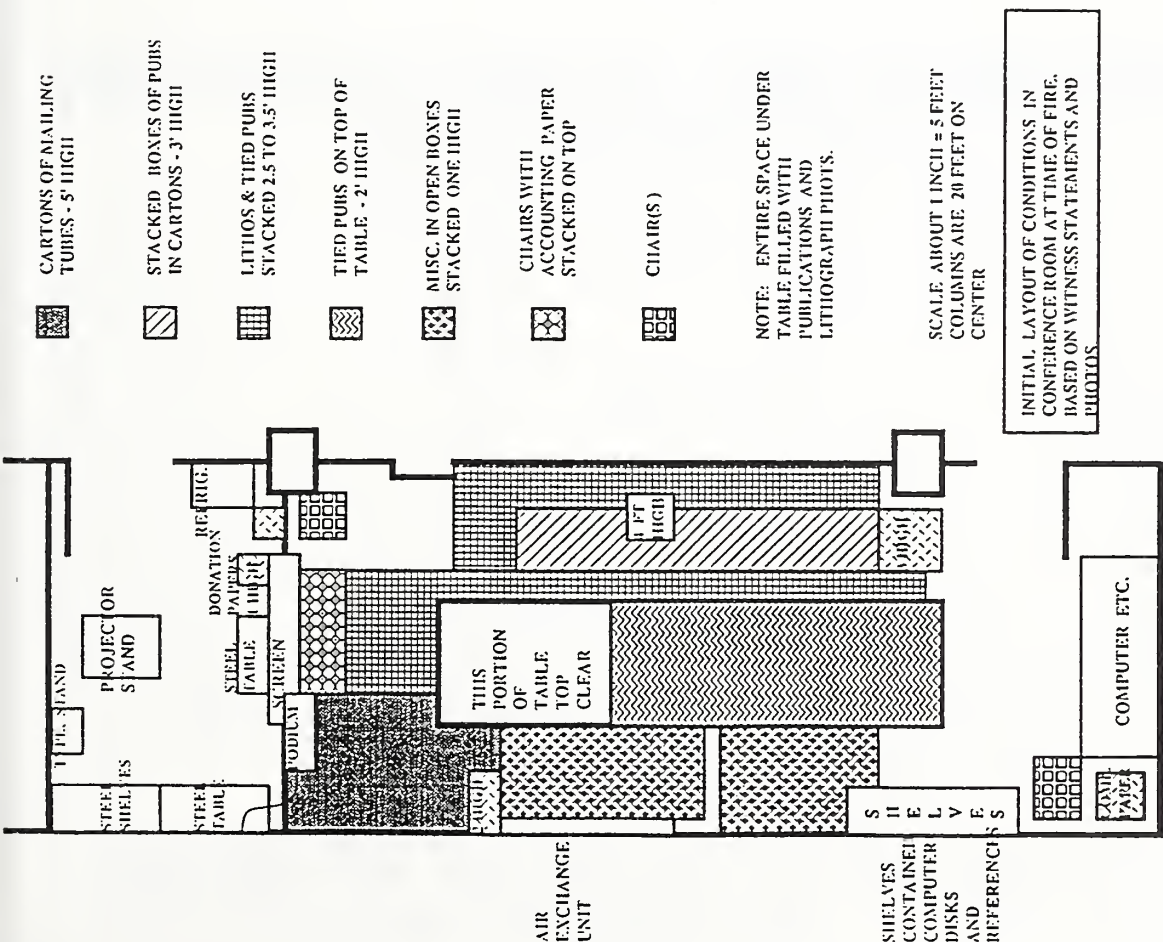


FIGURE 4. CONFERENCE ROOM ON MARCH 23, 1990

FIGURE 5. LIKELY ARRANGEMENT OF PODIUM

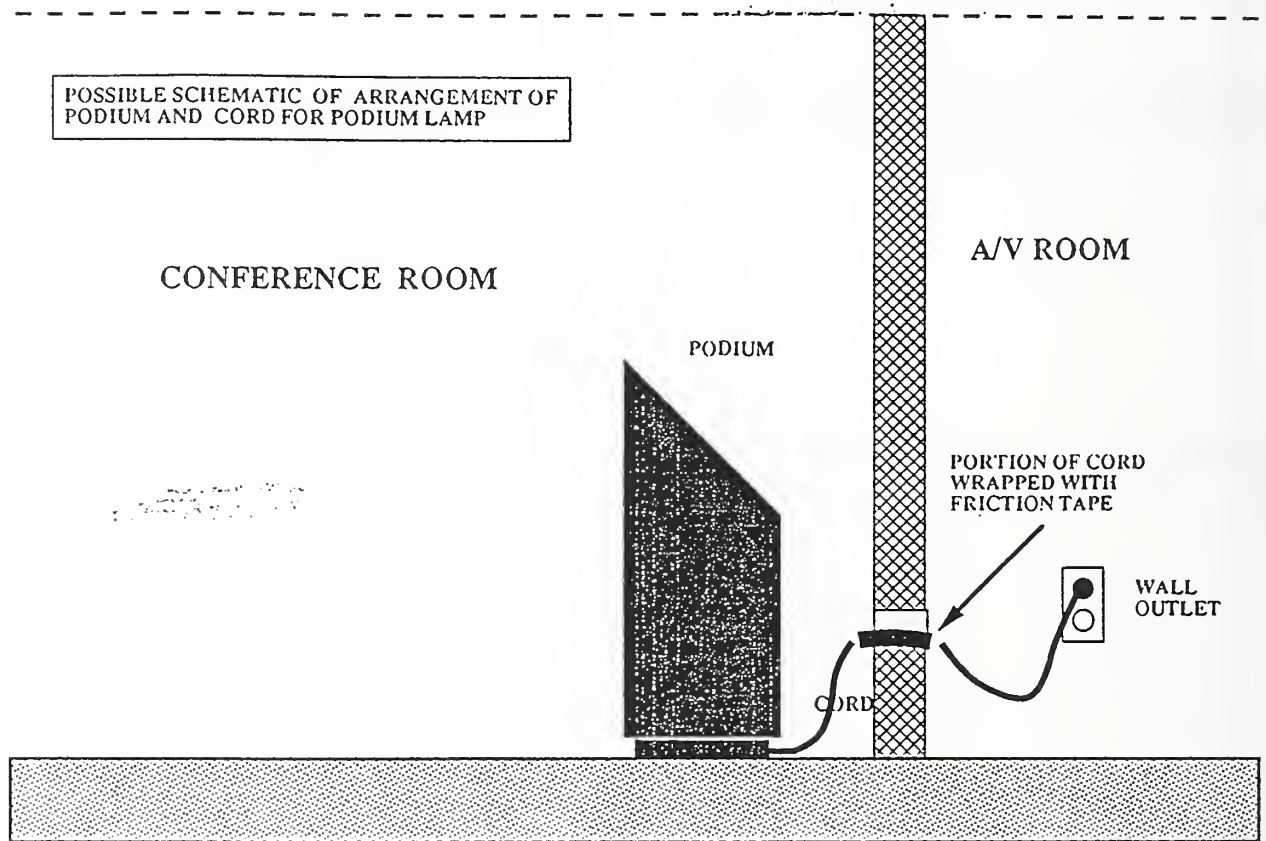


FIGURE 6. EST. FLAME EXTENSION
ABMC FIRE OF 3-23-1990

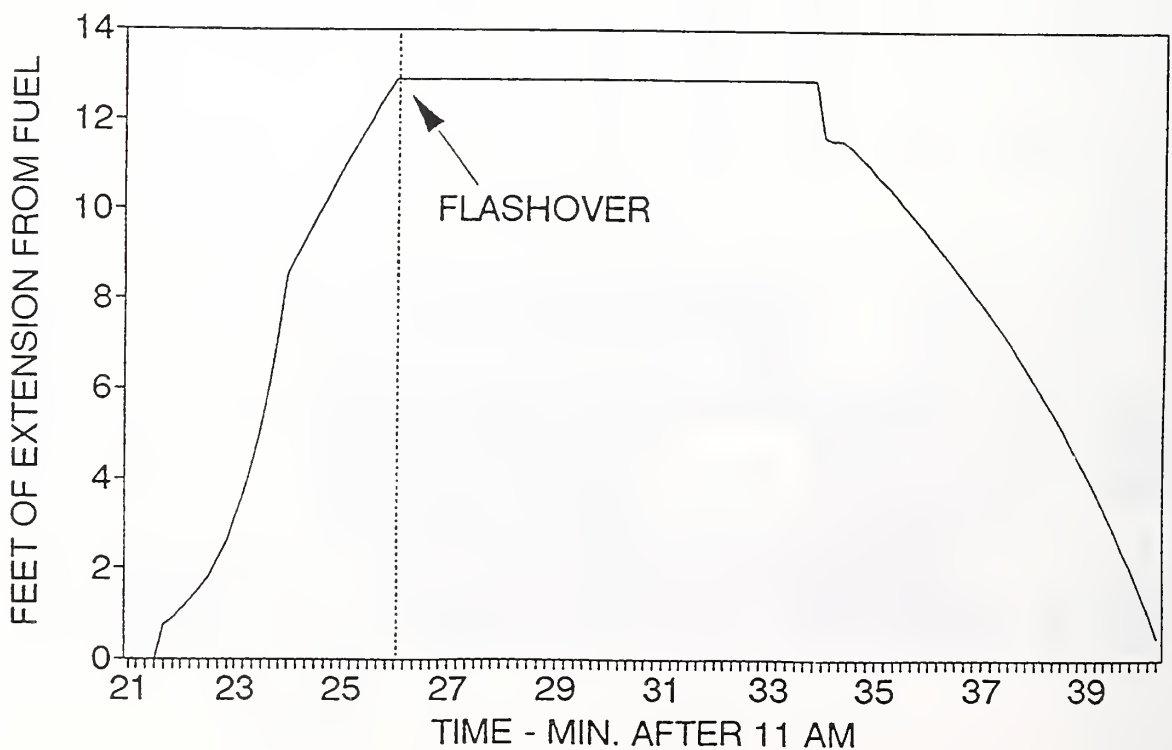


FIGURE 7. ESTIMATED FIRE SIZE

ABMC FIRE OF 3-23-1990

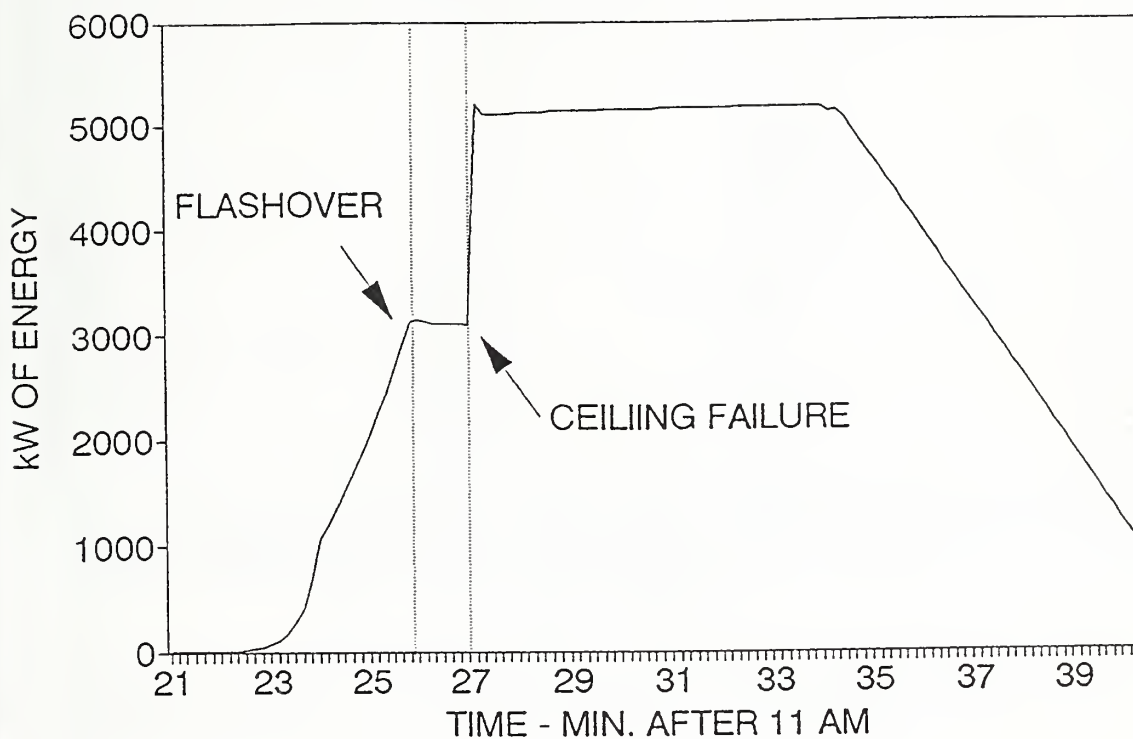
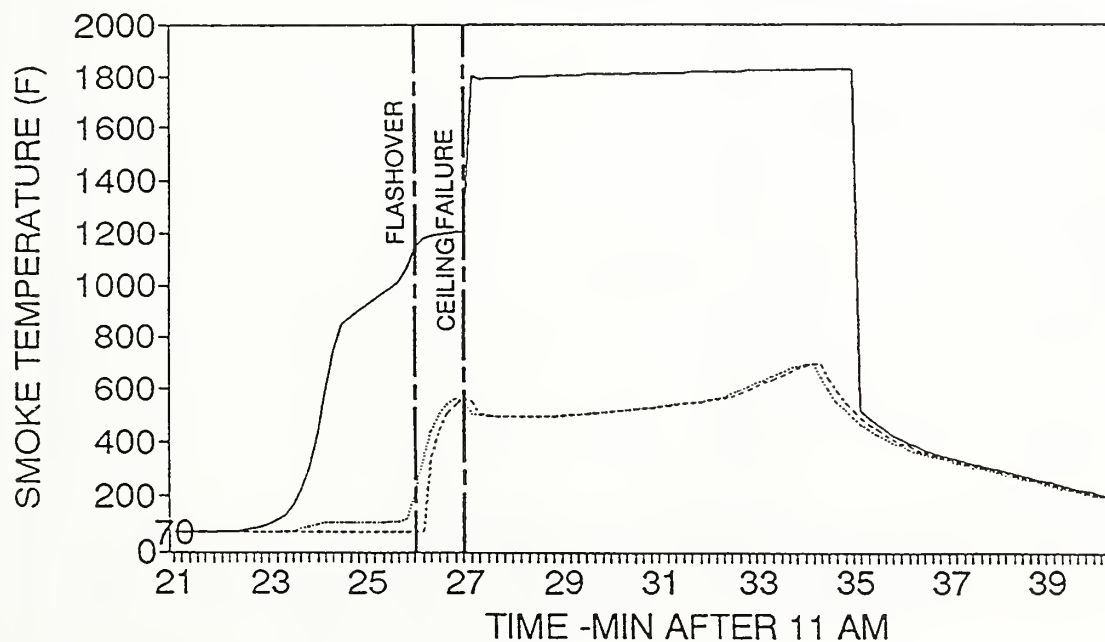


FIGURE 8. SMOKE TEMPERATURE

ABMC FIRE OF 3-23-1990



— CONF. RM. - - - SUITE OTHER AREAS

FIGURE 9. SMOKE LEVEL

ABMC FIRE OF 3-23-1990

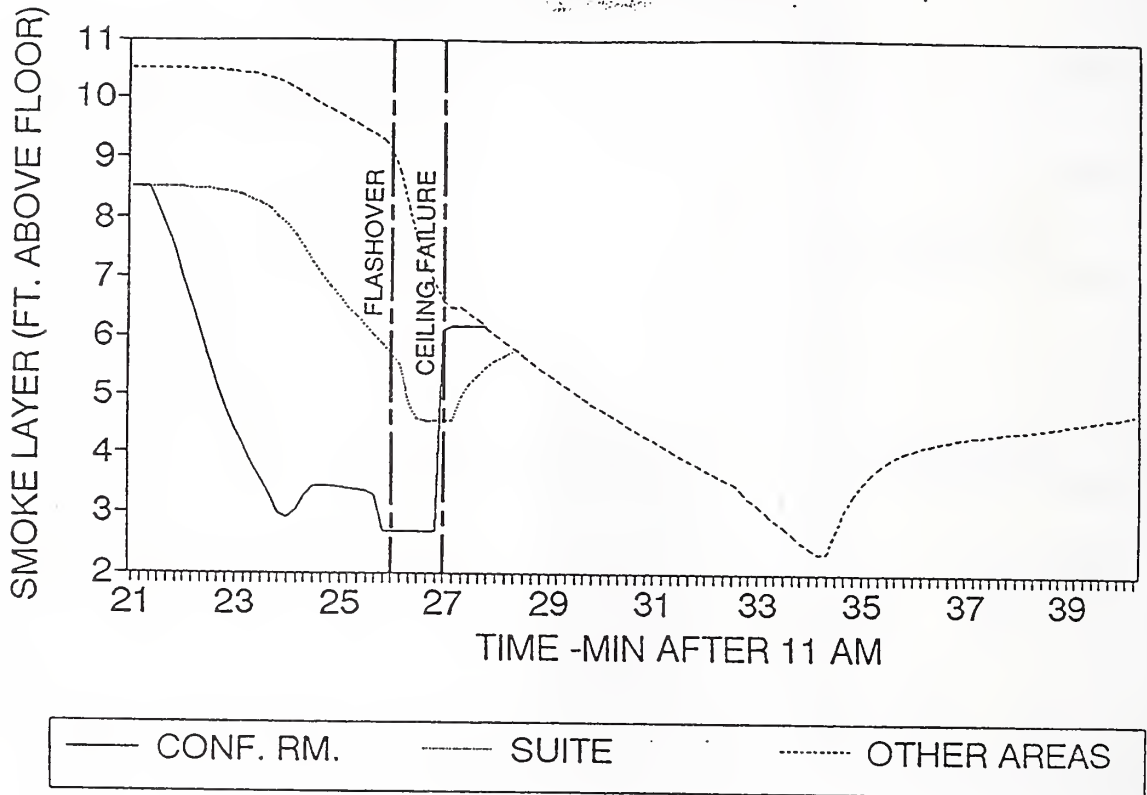


FIGURE 10. OXYGEN IN SMOKE

ABMC FIRE OF 3-23-1990

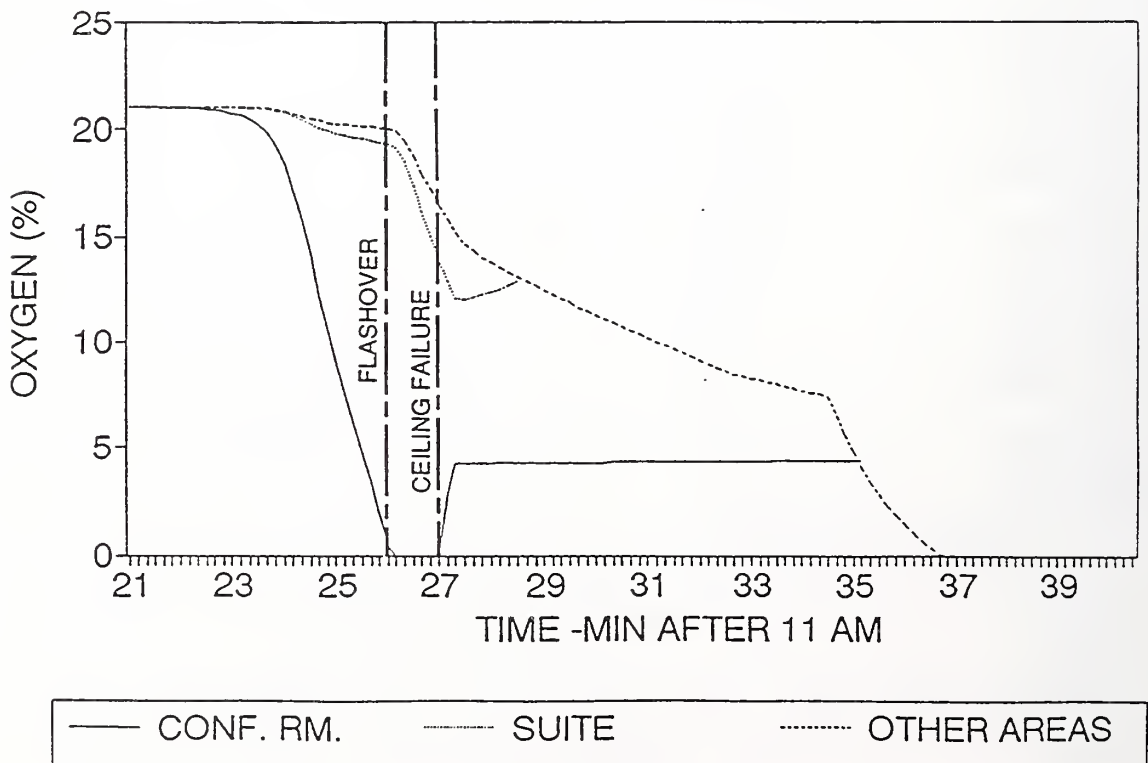


FIGURE 11. CO IN SMOKE

ABMC FIRE OF 3-23-1990

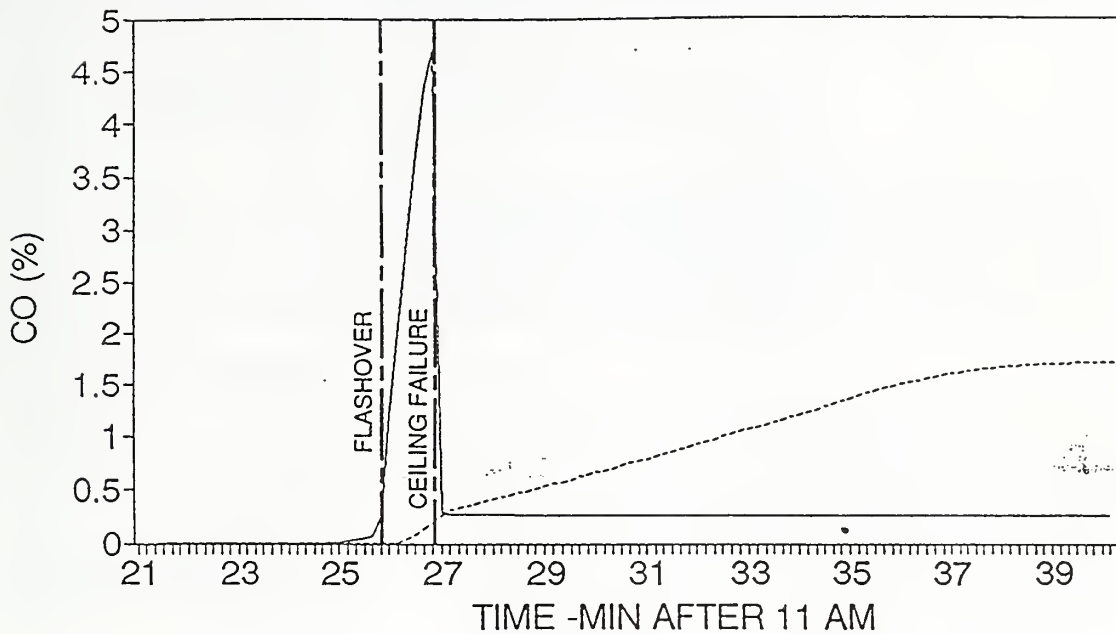


FIGURE 12. EST. VISION IN SMK.

ABMC FIRE OF 3-23-1990

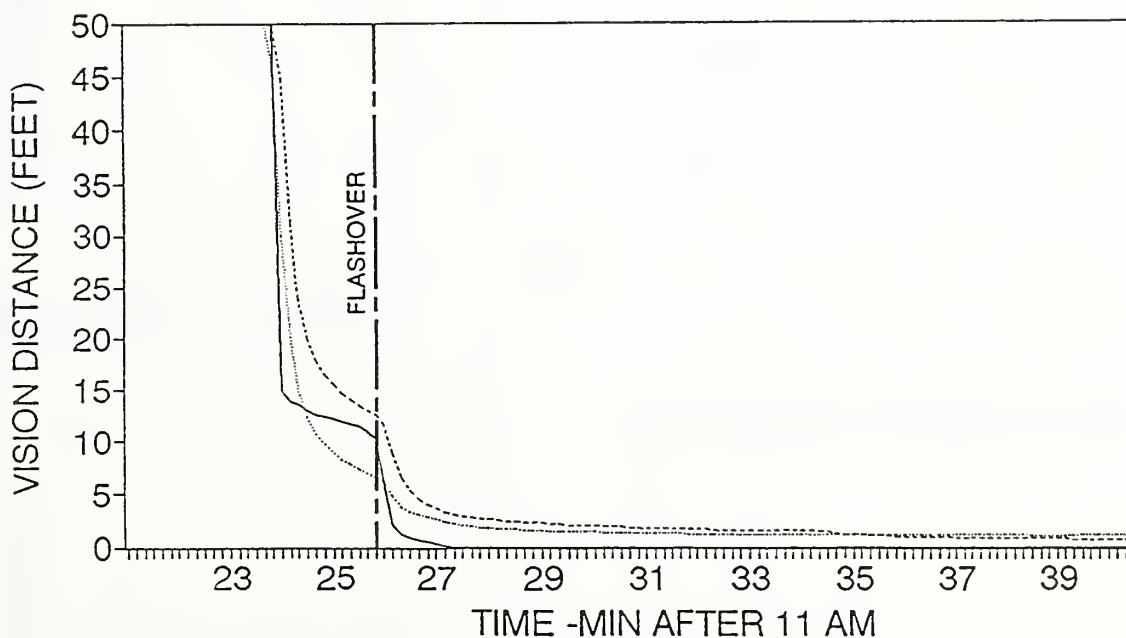


Diagram illustrating the layout and lighting/air fixture types for a CONFERENCE ROOM and an A/V ROOM.

CONFERENCE ROOM:

- Light/Air fixture return air type (indicated by a dashed line).
- Light/Air fixture supply air type (indicated by a solid line).
- open door (indicated by a dashed line).
- APPROXIMATE MEAN HEIGHT OF STORAGE IN CONFERENCE ROOM (indicated by a shaded area).
- door bell to be closed (indicated by a dashed line).

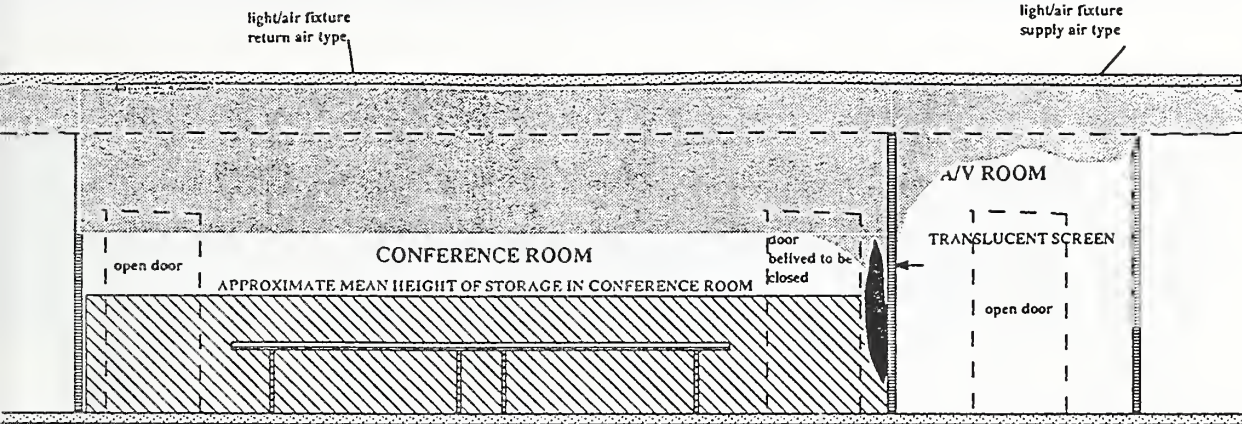
A/V ROOM:

- Light/Air fixture return air type (indicated by a dashed line).
- Light/Air fixture supply air type (indicated by a solid line).
- TRANSLUCENT SCREEN (indicated by a dashed line).
- open door (indicated by a dashed line).

AIR TRANSFER THROUGH LIGHT
FIXTURES - SOME SUPPLY, SOME
RETURN (LOCATIONS SHOWN MAY
NOT BE ACTUAL LOCATIONS AT
TIME OF FIRE.

- ☐ OCCUPANT AWAY FROM ABMC AT THIS TIME
- ☐ OCCUPANT IN ABMC SPACE AT THIS TIME

FIGURE 15. ELEVATION - CONFERENCE ROOM AREA - ABOUT 11:23 AM



FIRE IS ABOUT 100 KW (LARGE WASTE BASKET) SIZE. IS CLOSE TO THE MAXIMUM SIZE WHERE HAND FIRE EXTINGUISHER WOULD BE EFFECTIVE.

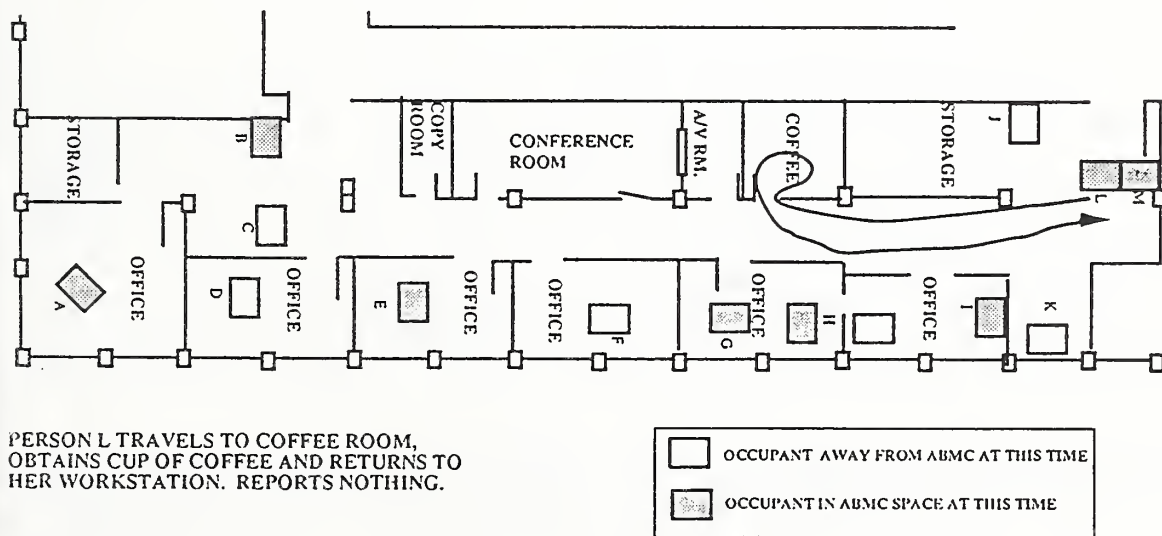
A NOTICEABLE THIN SMOKE IS ACCUMULATING AT THE CEILING. MORE IS BEING PULLED INTO THE CEILING RETURN AND SEEPING INTO THE A/V ROOM.

SMOKE IS WARMER BUT STILL ONLY ABOUT 100 DEGREE F. HOT GAS JET ACROSS CEILING IS CLOSE TO 200 DEGREES F.

SMOKE LEVEL IS DOWN TO OR PAST THE TOP OF THE OPEN DOOR. A SMALL AMOUNT IS PROBABLY FLOWING INTO THE ABMC CORRIDOR.

FLAME IS ABOUT 5 FEET HIGH.

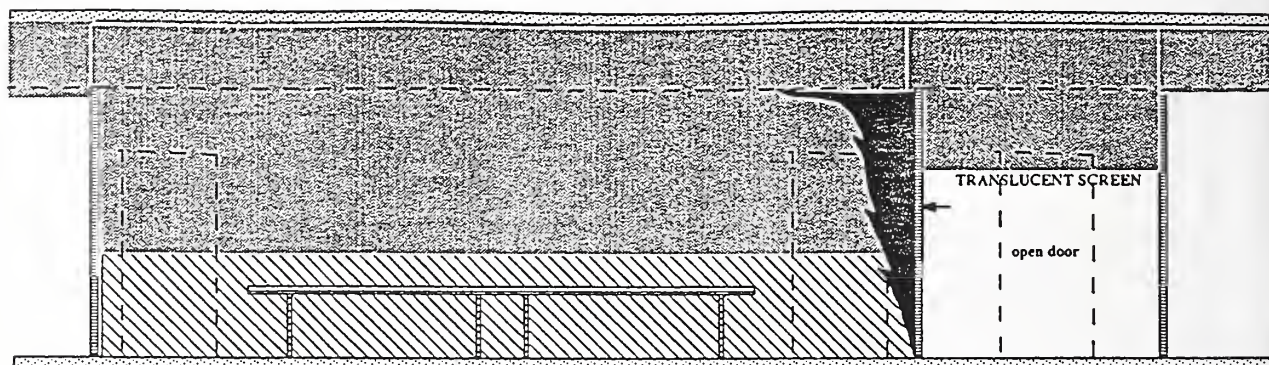
THIS APPROXIMATELY THE TIME WHEN A QUICK RESPONSE SPRINKLER WOULD HAVE OPERATED (IF PRESENT)



PERSON L TRAVELS TO COFFEE ROOM, OBTAINS CUP OF COFFEE AND RETURNS TO HER WORKSTATION. REPORTS NOTHING.

FIGURE 16. ACTIVITIES IN ABMC SUITE - ABOUT 11:22 TO 11:23 AM

FIGURE 17. ELEVATION - CONFERENCE ROOM AREA - ABOUT 11:24 AM



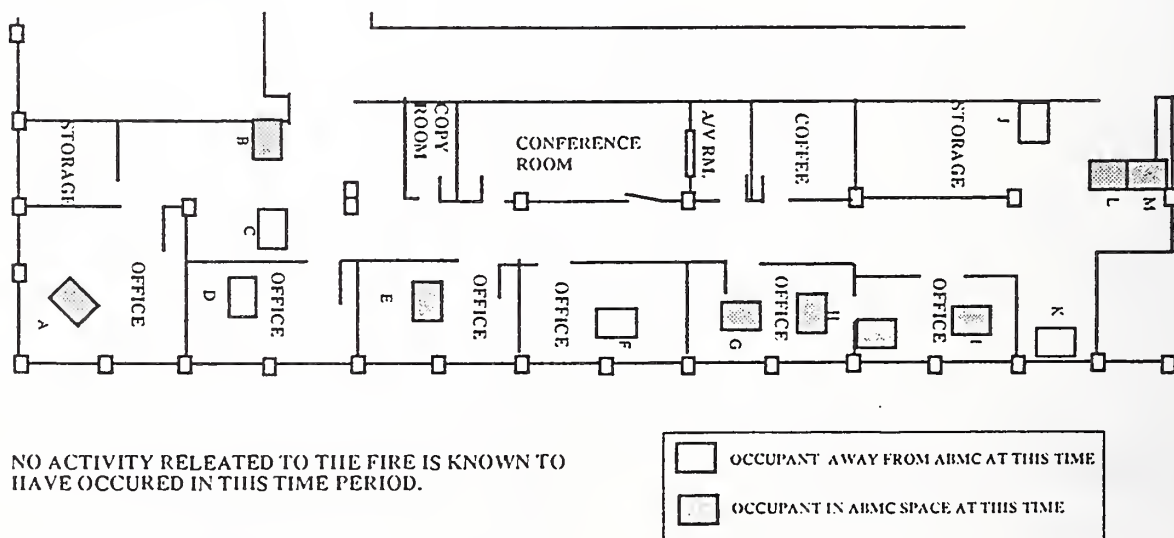
FIRE IS ABOUT 800KW (AS BIG AS A FULLY INVOLVED UPHOLSTERED EASY CHAIR.) SIZE IS TOO LARGE FOR HAND FIRE EXTINGUISHER ATTACK.

A GRAY SMOKE IS IN THE UPPER HALF OF THE ROOM. THE SMOKE IS CLEARLY EVIDENT BUT DOES NOT YET BLOCK OUT A SIGNIFICANT QUANTITY OF LIGHT FROM THE CEILING FIXTURES. THE SMOKE IN THE A/V ROOM HAS DESCENDED BELOW THE TOP OF THE DOOR OPENING. SMOKE IS BEGINNING TO BE RECIRCULATED BY THE BUILDING FANS.

SMOKE TEMPERATURE IS APPROACHING 400 F.

FLAME EXTENTION IS NOW IN THE RANGE OF 9-11 FEET AND STARTING TO BEND ACROSS THE CEILING.

A STANDARD SPRINKLER HEAD WOULD HAVE OPERATED ABOUT 30 SECONDS PRIOR TO THIS TIME (IF PRESENT)



NO ACTIVITY RELEATED TO THE FIRE IS KNOWN TO HAVE OCCURED IN THIS TIME PERIOD.

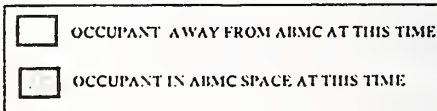
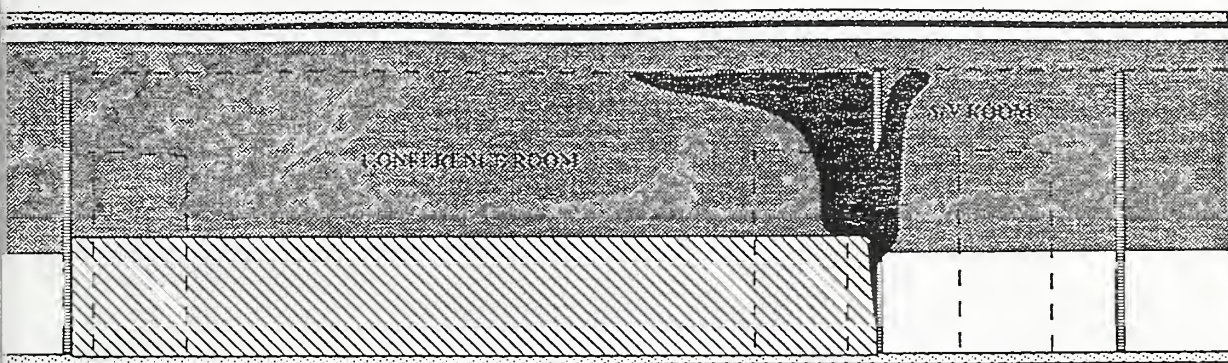


FIGURE 18. ACTIVITIES IN ABMC SUITE - ABOUT 11:23 TO 11:24 AM

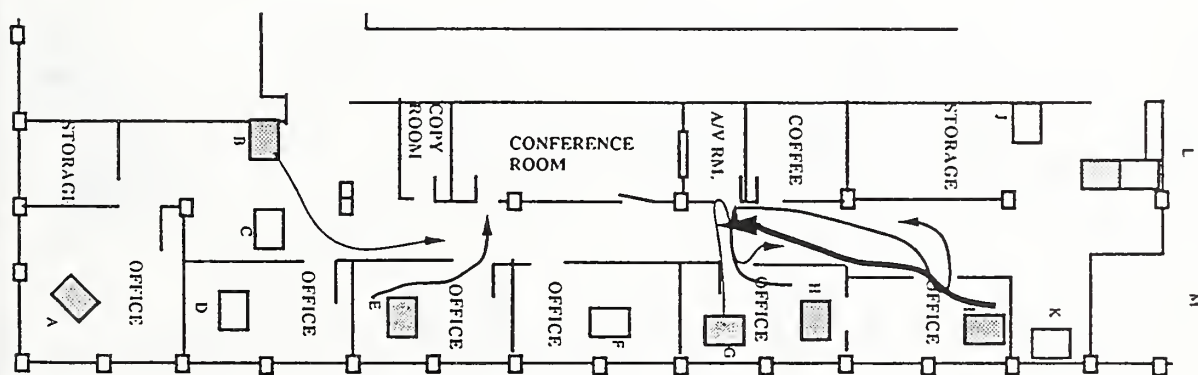
FIGURE 19. ELEVATION - CONFERENCE ROOM AREA - ABOUT 11:25 AM



FIRE SIZE HAS INCREASED TO ABOUT 2 MW. FLAMES ARE LAPPING ACROSS CEILING PROBABLY ALONG THE JUNCTION OF THE CEILING WITH THE SOUTH AND EAST WALLS.

OXYGEN IN THE SMOKE IS DOWN TO ABOUT 10% AND COMBUSTION EFFICIENCY DROPS. THIS RESULTS IN SHARP BLACKENING OF THE SMOKE AND A RISE IN THE CARBON MONOXIDED CONTENT.

THERE IS NO POSSIBILITY OF ENTERING THE ROOM AND LARGE QUANTITIES OF INTOLERABLE GASES ARE SPILLING OUT THE DOOR INTO THE ABMC SUITE



- PERSON G SMELLS SMOKE & NOTES HAZE. RISES FROM DESK, STEPS INTO HALL AND SEES SMOKE IN A/V RM. CALLS OUT "SMOKE". RETURNS TO OFFICE TO ALERT OTHERS.. SEARCHES FOR FIRE EXTINGUISHER.

- PERSON H HEARS PERSON G, LEAVES DESK, LOOKS INTO A/V ROOM SEES SMOKE AND GLOW, FEELS HEAT. RETURNED TO OFFICE, TOLD SUPERVISOR (PERSON I) AND STARTED BACK TOWARDS A/V ROOM.

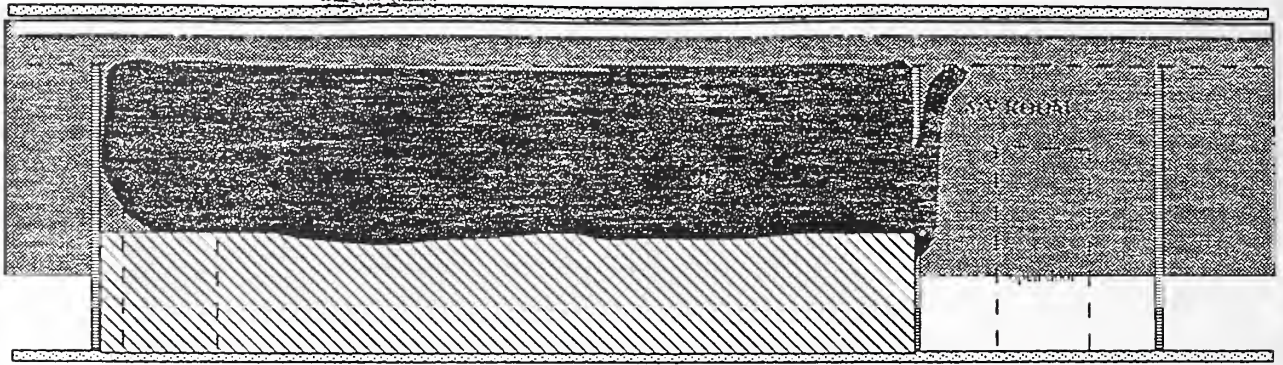
- PERSON I LEAVES DESK, GOES TO A/V ROOM. LOOKS IN, SEES BRIGHT GLOW AND SHADOW IMAGES ON TRANSLUCENT PROJECTION PANEL BETWEEN A/V ROOM AND CONFERENCE ROOM.

- PERSON B HEARS COMMOTION, LEAVES DESK APPROACHES CONFERENCE ROOM FROM WEST. LOOKS IN SEE FLAME AT CEILING, EXTENDING DOWN WALL. AFTER SURVEYING THE SCENE IN THE CORRIDOR, LOOKS AGAIN SEES FLAME EXTENDING FURTHER DOWN WALL.

- PERSON E HEARS PERSON G, LEAVES OFFICE AND GOES TO WEST DOOR OF CONFERENCE ROOM. LOOKS IN TOWARD EAST END, SEES A INTERMITTENT SHEET OF FIRE, 1 TO 2 FOOT WIDE AND EXTENDING SEVERAL FEET FROM THE BUILDING, RETREATS TO CORRIDOR AND CALLS FOR A FIRE EXTINGUISHER.

FIGURE 20. ACTIVITIES IN ABMC SUITE - ABOUT 11:24 TO 11:25 AM

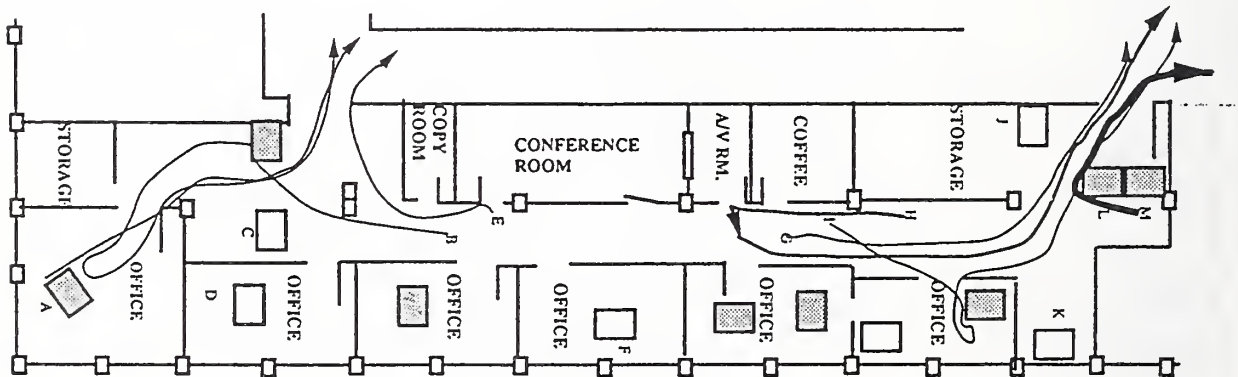
FIGURE 21 ELEVATION - CONFERENCE ROOM AREA - ABOUT 11:26 AM



FLASHOVER OCCURS - THE EXPOSED SURFACES OF ALL COMBUSTIBLE MATERIALS ATTEMPT TO IGNITE. THE ACTUAL BURNING IN THE ROOM IS LIMITED BY THE RATE THAT AIR CAN BE DRAWN INTO THE ROOM. UNBURNED FUEL GAS VENT AS FLAME INTO THE ABMC CORRIDOR.

THE TEMPERATURE IN THE CONFERENCE ROOM QUICKLY RISES TO THE RANGE OF 1200 DEGREES F. THE VIEW INTO THE DOOR IS A MIXTURE OF FLAME AND THICK BLACK SMOKE. OXYGEN IN THE SMOKE IN THE CONFERENCE ROOM DROPS TO NEAR ZERO. THE CARBON MONOXIDE CONCENTRATION IN THE SMOKE RISES TO 3 TO 4%.

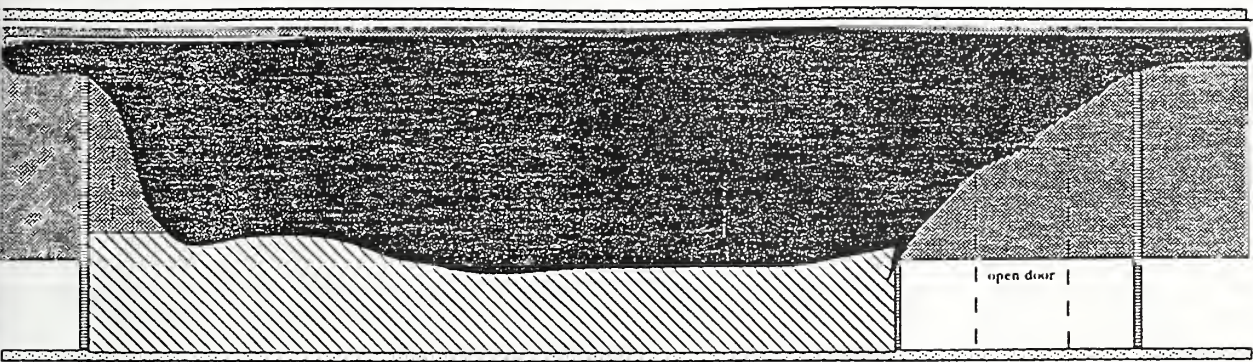
THE SMOKE FLOWS INTO THE ABMC SUITE DISTRIBUTING BLACK SOOT AND INTOLERABLE GAS CONCENTRATIONS. TEMPERATURE RISE IN THE SUITE (EXCEPT THAT DIRECTLY RADIATED BY THE FLAME FROM THE CONFERENCE ROOM) RISES ENOUGH TO BE INTOLERABLE TO HUMANS BUT IS WELL BELOW THAT REQUIRED TO IGNITE THE FURNITURE AND OTHER MATERIALS IN THE SUITE.



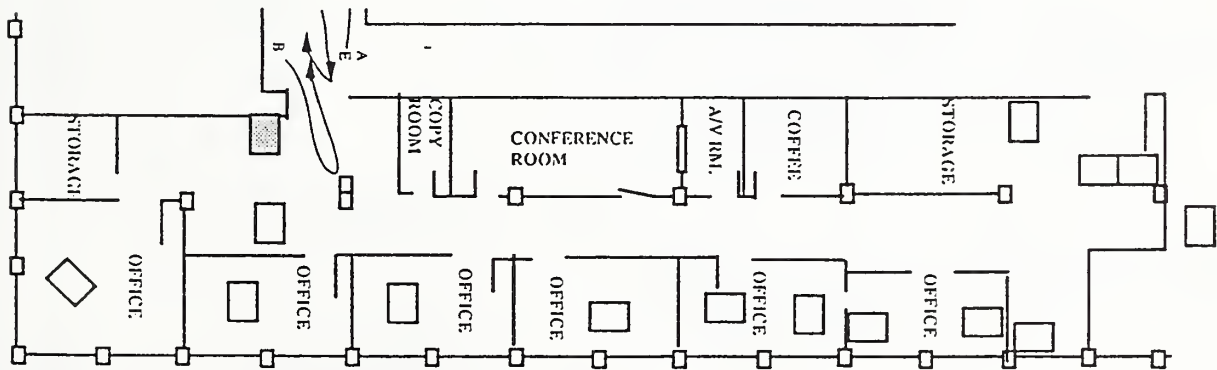
- PERSON G EXITS SUITE THROUGH EAST DOOR.
- PERSON H RETURNS TO A/V ROOM FOR SECOND LOOK SEES SMOKE COMING OUT OF A/V ROOM DOOR. LEVEL OF SMOKE IN A/V ROOM DOORWAY AT ABOUT CHEST LEVEL. THEN EXITS SPACE THROUGH EAST DOOR.
- PERSON I GOES TO DESK, GETS PURSE, EXITS SUITE THROUGH EAST DOOR.
- PERSON L SEEN LOOKING DOWN SUITE HALLWAY, THEN TURNS, JOINS PERSON M, LEAVES SUITE THROUGH EAST DOOR AND ATTEMPTS TO OPERATE FIRE ALARM BOX SLIGHTLY EAST OF EAST DOOR.
- PERSON M JOINS PERSON L IN LEAVING SUITE.
- PERSON B RETURNS TO DESK CALLS BUILDING MANAGER'S OFFICE TO REPORT FIRE, INFORMS PERSON A OF FIRE AND ESCORTS HIM TO BUILDING CORRIDOR, TURNS OVER GUIDANCE OF PERSON A TO PERSON E.
- PERSON E LOOKS AGAIN INTO CONFERENCE ROOM, SEES SMOKE "BOILING", CONCLUDES THAT IT IS NECESSARY TO LEAVE, EXITS THROUGH WEST DOOR, SEES PERSON B CALLING IN FIRE ALARM AS HE PASSES HER DESK, HEARS BUILDING FIRE ALARM AT THAT TIME.

FIGURE 22. ACTIVITIES IN ABMC SUITE - ABOUT 11:25 TO 11:27 AM

FIGURE 23. ELEVATION - CONFERENCE ROOM AREA - ABOUT 11:27 AM



CEILING FAILS (PROBABLY IN SECTIONS). FLAME IS VENTED INTO CEILING PLENUM SPACE. SMOKE ROUTE CHANGES. LITTLE, IF ANY, MORE SMOKE FLOWS THROUGH CONFERENCE ROOM DOOR INTO ABMC SPACE. DESTRUCTION CONTINUES IN THE CONFERENCE ROOM AND ADJACENT SPACES AND THE ENTIRE FLOOR RAPIDLY FILLS WITH SMOKE GENERATED BY THE FIRE, FLOWED INTO THE PLENUM SPACE AND DESCENDING INTO THE GENERAL FLOOR SPACE THROUGH THE CEILING LIGHTING FIXTURES AND OTHER CEILING OPENINGS. BY ABOUT 11:35 AM ENTIRE FLOOR IS FILLED WITH SMOKE TO A LEVEL 1 TO 2 FEET ABOVE THE FLOOR.



- PERSON E ESCORTS PERSON A INTO STAIRWELL, THEN RETURNS TO WEST ENTRANCE OF ABMC SUITE, CALLS IN TO ASSURE THAT ALL OCCUPANTS ARE OUT. FINDS B HAS RE-ENTERED SUITE.
- PERSON B RE-ENTERS SUITE, GETS PURSES FROM CLOSET AND LEAVES. SMOKE IS BLACK, AND IRRITATING. PERSON B ESTIMATES THAT SMOKE LEVEL IS BELOW HER WAIST.
- PERSONS B & E THEN LEAVE FLOOR.
- ALL PERSONS THAT HAVE EXITED FROM THE EAST DOOR TO THE SUITE ALSO HAVE EXITED FLOOR ALONG WITH THE OTHER OCCUPANTS OF THE FLOOR.



FIGURE 24. ACTIVITIES IN ABMC SUITE ABOUT 11:27+ AM

FIRE	PEOPLE	APPROXIMATE TIME	EXISTENT PROTECTION SYSTEMS	POTENTIAL PROTECTION SYSTEMS
FIRST FLAME		11:20		THE ITEMS LISTED IN THIS COLUMN DID NOT EXIST IN THE FIRE AREA. THE ENTRIES REPRESENT THE EXPECTED TIME OF OPERATION HAD THEY BEEN PRESENT.
		11:21		
FLAME 1 FT. HIGH	PERSONS F & K LEAVE ABMC	11:22		
SMOKE DOWN TO TOP OF DOOR OF CONF. RM.	PERSON L GETS COFFEE	11:23		SMOKE DETECTOR
FLAME 2-3 FT. HIGH				
FLAME TO CEILING	PERSON G SENSES SMOKE	11:24		QUICK RESPONSE SPRINKLER
	PERSONS B & E SEE FLAME IN CONF. RM,	11:25		STANDARD SPRINKLER
FLASHOVER IN CONFERENCE ROOM	PERSON SEES SMOKE "BOILING" IN CONF. RM	11:26		
	EVERYONE OUT OF ABMC SUITE			
CEILING FAILURE IN CONFERENCE RM.	PERSON B RE-ENTERS SUITE TO RETRIEVE BELONGINGS	11:27	FIRE ALARM BOX OPERATED	
		11:28	FIRE DEPT. RECEIVES ALARM	* THERE IS NO RECORD OF THE TIME WHEN THE FIRE DEPARTMENT ACTUALLY ARRIVED AT THE ABMC SUITE. IT PROBABLY OCCURRED BETWEEN 11:35 A 11:40
		11:29		
		11:30	FIRST FIRE COMPANY ARRIVES AT BUILDING	

FIGURE 25. TIME LINE OF EVENTS

APPENDIX A

Printout of results of FIRE SIMULATOR run for the Conference Room

The printout contained in this appendix is actually the combination of two runs of FIRE SIMULATOR. The two runs were identical except that the run used for the first 210 seconds estimated the specific extinction coefficient as 30% of that estimated for the remainder of the run.

Also at 330 seconds into the run, the size of the room opening was revised to simulate massive failure of the ceiling system.

```

FIRE SIMULATOR
(VER 2.00)

INPUT DATA USED FOR RUN OF: 09-26-1990 17:49:09
DATA FILE USED: CON-MIX1.IN AS OF 09/26/90 17:48:34
RUN TITLE: 20 MASS CONFERENCE ROOM PRIOR TO CEILING FAILURE 04-10-1990
ASCII FILE NAME: CON-MIX1.PRN

HEAT OF COMBUSTION: 8607.33 BTU/lb 20000.00 KJ/Kg
SPECIFIC EXTINCTION COEFFICIENT: .03
FLASHOVER TEMPERATURE: 1112.00 F
OXYGEN STARVATION THRESHOLD: 10.00 % BY VOLUME 600.00 C
RADIANT ENERGY FRACTION (FROM FLAME): .35
MAXIMUM PRE FLASHOVER ENERGY LOSS: .96

THERE IS NO SPRINKLER/HEAT DETECTOR DEFINED
THERE IS NO SMOKE DETECTOR DEFINED

DESCRIPTION OF INITIAL OUTSIDE OPENING:
HEIGHT OF OPENING: 6.60 ft 2.01 m
WIDTH OF OPENING: 3.00 ft 0.91 m
HEIGHT OF SILL ABOVE FLOOR: 0.00 ft 0.00 m

SPACIAL DIMENSIONS OF ROOM:
ROOM HEIGHT: 8.50 ft 2.59 m
ROOM FLOOR AREA: 299.99 ft^2 27.87 m^2
ROOM WALL PERIMETER: 74.00 ft 22.56 m
ROOM IS RECTANGULAR: 25.00 ft 12.00 ft 7.62 m BY 3.66 m

DESCRIPTION OF CEILING MATERIALS:
100 % MINERAL CEILING 1 IN 25.4 mm

DESCRIPTION OF WALL MATERIALS:
100 % GYPSUM BOARD .5 IN 12.7 mm

THERE IS NO HVAC DEFINED

FIRE HEIGHT: 0.00 ft 0.00 m

FAST EXP. TO 1M THEN FAST T-SQ. TO 8MW 1 MIN STEADY THEN DECAY TO 0
FIRE DESCRIPTION USED CAME FROM FILEFILE: COE-8EX.FIR 4-14-1990
A HALT FLAG IS SET FOR TIME = 330 Sec

TIME -----TEMP----- --LAYER----- --FIRE-----
sec F C ft m kW BTU/sec
0.0 70.0 21.1 8.5 2.6 0.1
VISION DISTANCE (Smoke layer) = 10000.00 m 32808.40 ft
SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0000 %
SMOKE VENT RATE IS 0 cfm 0.00 csm
ENTHALPY (Heat content) 0 btu/sec 0 kW
INSIDE FLOW OF UNBURNED FUEL POTENTIAL 0 BTU/SEC 0 kW

30.0 73.7 23.1 7.4 2.3 4.0 3.8
VISION DISTANCE (Smoke layer) = 284.42 m 933.13 ft

```


SCORE VENT RATE IS 0 CFM 0.00 CSM
ENTHALPY (Heat content) 0 BTU/SEC 0 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

60.0 80.2 26.8 6.1 1.9 16.2 15.4
VISION DISTANCE (smoke layer) = 126.41 m 414.73 ft
SMOKE GASES : OXYGEN = 20.9 % : CO = 0.0000 : CO2 = 0.0711 %
SMOKE VENT RATE IS 27 CFM 0.01 CSM
ENTHALPY (Heat content) 0 BTU/SEC 0 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

90.0 100.3 37.9 4.8 1.5 65.1 61.8
VISION DISTANCE (smoke layer) = 54.23 m 177.91 ft
SMOKE GASES : OXYGEN = 20.7 % : CO = 0.0000 : CO2 = 0.1879 %
SMOKE VENT RATE IS 359 CFM 0.17 CSM
ENTHALPY (Heat content) 3 BTU/SEC 3 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

120.0 168.9 76.1 3.8 1.2 261.9 248.4
VISION DISTANCE (smoke layer) = 27.13 m 89.01 ft
SMOKE GASES : OXYGEN = 20.2 % : CO = 0.0000 : CO2 = 0.5686 %
SMOKE VENT RATE IS 1250 CFM 0.59 CSM
ENTHALPY (Heat content) 31 BTU/SEC 32 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

150.0 438.2 225.7 3.0 0.9 1053.6 999.4
VISION DISTANCE (smoke layer) = 15.14 m 49.66 ft
SMOKE GASES : OXYGEN = 18.3 % : CO = 0.0003 : CO2 = 1.9184 %
SMOKE VENT RATE IS 3569 CFM 1.68 CSM
ENTHALPY (Heat content) 228 BTU/SEC 240 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

180.0 850.7 454.8 3.3 1.0 1503.0 1425.6
VISION DISTANCE (smoke layer) = 13.26 m 43.49 ft
SMOKE GASES : OXYGEN = 14.0 % : CO = 0.0033 : CO2 = 5.0523 %
SMOKE VENT RATE IS 4708 CFM 2.22 CSM
ENTHALPY (Heat content) 436 BTU/SEC 459 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

210.0 923.7 495.4 3.4 1.0 2045.0 1939.7
VISION DISTANCE (smoke layer) = 12.45 m 40.85 ft
SMOKE GASES : OXYGEN = 9.1 % : CO = 0.0154 : CO2 = 8.7762 %
SMOKE VENT RATE IS 4492 CFM 2.12 CSM
ENTHALPY (Heat content) 431 BTU/SEC 454 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

240.0 990.5 532.5 3.4 1.0 2671.0 2533.4
VISION DISTANCE (smoke layer) = 3.49 m 11.45 ft
SMOKE GASES : OXYGEN = 4.7 % : CO = 0.0385 : CO2 = 12.0289 %
SMOKE VENT RATE IS 4786 CFM 2.26 CSM
ENTHALPY (Heat content) 472 BTU/SEC 498 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

268.0 1118.2 603.4 3.2 1.0 3331.8 3160.2
VISION DISTANCE (smoke layer) = 2.98 m 9.78 ft
SMOKE GASES : OXYGEN = 0.9 % : CO = 0.0720 : CO2 = 14.9325 %
SMOKE VENT RATE IS 5384 CFM 2.54 CSM
ENTHALPY (Heat content) 555 BTU/SEC 584 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

COUPPER LEVEL TEMP. INDICATES THAT FLASHOVER HAS OCCURRED

POST FLASHOVER
COMBUSTION EFFICIENCY 100.00
HEAT OF COMBUSTION 20000.0 KJ/Kg 8607 BTU/lb
BASE HEAT OF GASIFICATION 2.0 KJ/g 861 BTU/lb
FUEL LOAD 40.00 lb/ft² 195.30 kg/m²
% BURNABLE = 10.00
HORIZONTAL COMB. SURFACE (%) 80.00
VERTICAL COMB. SURFACE (%) 10.00
HORIZ. COMB. SURF. > 1/4 IN. (%) 80.00
VERT. COMB. SURF. > 1/4 IN. (%) 10.00
HORIZ. COMB. SURF. > 1 IN. (%) 80.00
VERT. COMB. SURF. > 1 IN. (%) 10.00
DURATION (SEC) = 863
INSIDE OPENING IS 6.60 ft X 3.00 ft X 0.00 ft 2.012 m X 0.914 m X 0.000 m
OUTSIDE OPENING IS 0.00 ft X 0.00 ft X 0.00 ft 0.000 m X 0.000 m X 0.000 m

270.0 1139.3 615.2 2.7 0.8 3153.0 2990.6
VISION DISTANCE (smoke layer) = 1.93 m 6.32 ft
SMOKE GASES : OXYGEN = 0.4 % : CO = 0.2638 : CO2 = 14.9495 %
SMOKE VENT RATE IS 7122 CFM 3.36 CSM
ENTHALPY (Heat content) 739 BTU/SEC 779 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 637 BTU/SEC 671 KW

300.0 1195.5 646.4 2.7 0.8 3112.1 2951.8
VISION DISTANCE (smoke layer) = 0.27 m 0.89 ft
SMOKE GASES : OXYGEN = 0.0 % : CO = 2.9005 : CO2 = 12.7877 %
SMOKE VENT RATE IS 7372 CFM 3.48 CSM
ENTHALPY (Heat content) 778 BTU/SEC 820 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 8,676 BTU/SEC 9,144 KW

330.0 1205.0 651.7 2.7 0.8 3105.2 2945.2
VISION DISTANCE (smoke layer) = 0.15 m 0.48 ft
SMOKE GASES : OXYGEN = 0.0 % : CO = 4.7065 : CO2 = 10.9818 %
SMOKE VENT RATE IS 7414 CFM 3.50 CSM
ENTHALPY (Heat content) 784 BTU/SEC 827 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 8,676 BTU/SEC 9,144 KW

330.0 1205.0 651.7 2.7 0.8 3105.2 2945.2
VISION DISTANCE (smoke layer) = 0.15 m 0.48 ft
SMOKE GASES : OXYGEN = 0.0 % : CO = 4.7065 : CO2 = 10.9818 %
SMOKE VENT RATE IS 7414 CFM 3.50 CSM
ENTHALPY (Heat content) 784 BTU/SEC 827 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 8,676 BTU/SEC 9,144 KW

360.0 1791.2 977.3 6.2 1.9 8588.4 8146.1
VISION DISTANCE (smoke layer) = 0.03 m 0.09 ft
SMOKE GASES : OXYGEN = 4.2 % : CO = 0.2690 : CO2 = 12.2587 %
SMOKE VENT RATE IS 314 CFM 0.15 CSM
ENTHALPY (Heat content) 37 BTU/SEC 39 KW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 KW

390.0 1795.4 979.7 6.2 1.9 8578.5 8136.7
VISION DISTANCE (smoke layer) = 0.02 m 0.05 ft

APPENDIX B

Printout of results of FIRE SIMULATOR run for the ABMC suite.

This run considers the suite as a closed space until 270 seconds, at which time it assumes that both of the suite doors are opened.

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FIRE SIMULATOR
[VER 2.00]

INPUT DATA USED FOR RUN OF: 09-26-1990 17:51:55
DATA FILE USED: SU-MIX-X.IN AS OF 09/26/90 17:51:28
RUN TITLE: ABMC - SUITE SPACE - OUTFLOW FROM CONF. ROOM DOOR 04-21-1990
ASCII FILE NAME: SU-MIX-X.PRN

HEAT OF COMBUSTION: 7685.12 BTU/lb 17857.14 kJ/Kg
SPECIFIC EXTINCTION COEFFICIENT: .10
FLASHOVER TEMPERATURE: 1112.00 F
OXYGEN STARVATION THRESHOLD: 10.00 % by VOLUME 600.00 C
RADIANT ENERGY FRACTION (FROM FLAME): .35
MAXIMUM PRE FLASHOVER ENERGY LOSS: $1.00

THERE IS NO SPRINKLER/HEAT DETECTOR DEFINED
THERE IS NO SMOKE DETECTOR DEFINED
THERE IS NO INITIAL OUTSIDE OPENING DEFINED

SPACIAL DIMENSIONS OF ROOM:
ROOM HEIGHT: 8.00 ft 2.44 m
ROOM FLOOR AREA: 2499.92 ft^2 232.25 m^2
ROOM WALL PERIMETER: $9000.00 ft $2743.20 m
ROOM IS NOT RECTANGULAR

DESCRIPTION OF CEILING MATERIALS:
100 % MINERAL CEILING 1 IN 25.4 mm

DESCRIPTION OF WALL MATERIALS:
100 % GYPSUM BOARD .5 IN 12.7 mm

DESCRIPTION OF HVAC:
COMBUSTION EFFICIENCY OF HVAC AIR: 20.00 %
AIR CHANGES PER HOUR: 3.00

FIRE HEIGHT: 0.00 ft 0.00 m

OUTPUT FIRE FROM RNTOL RUNNING CON-MIX1.IN AS INPUT - ADJ TO 5MW MAX
FIRE DESCRIPTION USED CAME FROM FILEFILE: FIRE.FIR 09-14-1990
A HALT FLAG IS SET FOR TIME = 270 Sec

TIME -----TEMP----- LAYER-----FIRE-----
sec F C ft m kW BTU/sec
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft 0.1
SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0000 %
30.0 70.5 21.4 8.0 2.4 0.0 0.0
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft
SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0009 %
60.0 70.2 21.2 8.0 2.4 0.1 0.1
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft

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SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0011 %
VISION DISTANCE (smoke layer) = 21.4 = 7.9 = 2.4 = 3.2 = 3.0
SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0147 %
120.0 74.5 23.6 7.6 2.3 32.3 30.6
VISION DISTANCE (smoke layer) = 35.82 = 117.52 ft
SMOKE GASES : OXYGEN = 20.9 % : CO = 0.0000 : CO2 = 0.0764 %
150.0 90.7 32.6 7.2 2.2 239.9 227.5
VISION DISTANCE (smoke layer) = 9.15 = 30.01 ft
SMOKE GASES : OXYGEN = 20.6 % : CO = 0.0000 : CO2 = 0.2957 %
180.0 107.0 41.7 6.5 2.0 459.5 435.8
VISION DISTANCE (smoke layer) = 3.77 = 12.36 ft
SMOKE GASES : OXYGEN = 20.1 % : CO = 0.0004 : CO2 = 0.7273 %
210.0 100.0 37.8 6.0 1.8 454.1 430.7
VISION DISTANCE (smoke layer) = 2.74 = 8.98 ft
SMOKE GASES : OXYGEN = 19.7 % : CO = 0.0010 : CO2 = 0.9985 %
240.0 98.2 36.8 5.5 1.7 497.6 472.0
VISION DISTANCE (smoke layer) = 2.26 = 7.41 ft
SMOKE GASES : OXYGEN = 19.5 % : CO = 0.0016 : CO2 = 1.2034 %
270.0 106.2 41.2 5.0 1.5 1450.0 1375.3
VISION DISTANCE (smoke layer) = 1.91 = 6.27 ft
SMOKE GASES : OXYGEN = 19.2 % : CO = 0.0027 : CO2 = 1.4219 %
270.0 106.2 41.2 5.0 1.5 1450.0 1375.3
VISION DISTANCE (smoke layer) = 1.91 = 6.27 ft
SMOKE GASES : OXYGEN = 19.2 % : CO = 0.0030 : CO2 = 1.4382 %
SMOKE VENT RATE IS 0 cfm 0.00 csm
ENTHALPY (Heat content) 0 btu/sec 0 kW
INSIDE FLOW OF UNBURNED FUEL POTENTIAL 0 BTU/SEC 0 kW
300.0 225.1 107.3 2.9 0.9 5270.0 4998.6
VISION DISTANCE (smoke layer) = 1.63 = 5.34 ft
SMOKE GASES : OXYGEN = 16.7 % : CO = 0.0801 : CO2 = 3.2333 %
SMOKE VENT RATE IS 3049 cfm 1.44 csm
ENTHALPY (Heat content) 107 btu/sec 113 kW
INSIDE FLOW OF UNBURNED FUEL POTENTIAL 0 BTU/SEC 0 kW
330.0 234.1 112.3 3.2 1.0 5270.0 4998.6
VISION DISTANCE (smoke layer) = 1.56 = 5.11 ft
SMOKE GASES : OXYGEN = 13.8 % : CO = 0.2620 : CO2 = 5.3152 %
SMOKE VENT RATE IS 3089 cfm 1.46 csm
ENTHALPY (Heat content) 113 btu/sec 120 kW
INSIDE FLOW OF UNBURNED FUEL POTENTIAL 0 BTU/SEC 0 kW
360.0 215.9 102.2 3.9 1.2 39.4 37.4
VISION DISTANCE (smoke layer) = 1.23 = 4.04 ft
SMOKE GASES : OXYGEN = 13.1 % : CO = 0.2378 : CO2 = 5.9694 %
SMOKE VENT RATE IS 1457 cfm 0.69 csm
ENTHALPY (Heat content) 49 btu/sec 52 kW
INSIDE FLOW OF UNBURNED FUEL POTENTIAL 0 BTU/SEC 0 kW
390.0 210.6 99.2 4.3 1.3 39.7 37.7
VISION DISTANCE (smoke layer) = 1.13 = 3.69 ft

SMOKE GASES : OXYGEN = 13.3 % : CO = 0.1574 : CO2 = 5.8959 %
SMOKE VENT RATE IS 1163 cfm 0.55 csm
ENTHALPY (Heat content) 38 btu/sec 40 kW
INSIDE FLOW OF UNBURNED FUEL POTENTIAL 0 BTU/SEC 0 kW
CO=====RUN COMPLETED=====

APPENDIX C

Printout of results of FIRE SIMULATOR run for 5th floor

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FIRE SIMULATOR
[VER 2.00]

INPUT DATA USED FOR RUN OF: 09-26-1990 17:54:17
DATA FILE USED: FLR-MIX2.IN AS OF 09/26/90 17:54:04

RUN TITLE:
COE - FLR AS ONE ROOM - EXTRA PERIMETER FOR PARTITIONS -FIRE A.D. 9-15-90

ASCII FILE NAME: FLR-MIX2.PRN

HEAT OF COMBUSTION: 8607.33 BTU/lb 20000.00 KJ/Kg
SPECIFIC EXTINGUITION COEFFICIENT: .10
FLASHOVER TEMPERATURE: 2600.00 F 1426.67 C
OXYGEN STARVATION THRESHOLD: 10.00 % by VOLUME
RADIANT ENERGY FRACTION (FROM FLAME): .35
MAXIMUM PRE FLASHOVER ENERGY LOSS: .90

THERE IS NO SPRINKLER/HEAT DETECTOR DEFINED
THERE IS NO SMOKE DETECTOR DEFINED

THERE IS NO INITIAL OUTSIDE OPENING DEFINED

SPACIAL DIMENSIONS OF ROOM:
ROOM HEIGHT: 10.51 ft 3.20 m
ROOM FLOOR AREA: 9999.35 ft^2 928.97 m^2
ROOM WALL PERIMETER: 11500.00 ft 457.20 m
ROOM IS NOT RECTANGULAR

DESCRIPTION OF CEILING MATERIALS:
25 % CONCRETE 7 IN 177.8 mm
75 % GYPSUM BOARD .5 IN 12.7 mm

DESCRIPTION OF WALL MATERIALS:
100 % GYPSUM BOARD .5 IN 12.7 mm

THERE IS NO HVAC DEFINED

FIRE HEIGHT: 1.00 ft 0.30 m

FIRE BASED ON EXFLUENT FROM CONF ROOM ADJUSTED FOR O2 REDUCTION
FIRE DESCRIPTION USED CAME FROM FILEFILE: ADJ-FLR.FIR 09-13-1990

TIME -----TEMP----- LAYER-----FIRE-----
sec F C ft m kW BTU/sec
0.0 70.0 21.1 10.5 3.2 0.1 0.1
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft
SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0000 %
30.0 70.0 21.1 10.5 3.2 0.0 0.0
VISION DISTANCE (smoke layer) = 1945.35 m 6382.38 ft
SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0012 %
60.0 70.0 21.1 10.5 3.2 0.1 0.1
VISION DISTANCE (smoke layer) = 2138.17 m 7015.00 ft
SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0012 %

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VISION DISTANCE (smoke layer) =	259.99 m	852.99 ft	0.0105 %
SMOKE GASES : OXYGEN =	21.0 %	CO = 0.0000	CO2 = 0.0105 %
VISION DISTANCE (smoke layer) =	22.3	10.4 m	3.2
SMOKE GASES : OXYGEN =	20.9 %	CO = 0.0000	CO2 = 0.0535 %
VISION DISTANCE (smoke layer) =	29.0	10.2 m	3.1
SMOKE GASES : OXYGEN =	20.7 %	CO = 0.0000	CO2 = 0.2017 %
VISION DISTANCE (smoke layer) =	39.1	10.0 m	3.0
SMOKE GASES : OXYGEN =	20.4 %	CO = 0.0002	CO2 = 0.4566 %
VISION DISTANCE (smoke layer) =	40.2	9.7 m	3.0
SMOKE GASES : OXYGEN =	20.2 %	CO = 0.0003	CO2 = 0.5940 %
VISION DISTANCE (smoke layer) =	41.7	9.5 m	2.9
SMOKE GASES : OXYGEN =	20.1 %	CO = 0.0005	CO2 = 0.6833 %
VISION DISTANCE (smoke layer) =	49.5	9.2 m	2.8
SMOKE GASES : OXYGEN =	19.9 %	CO = 0.0009	CO2 = 0.7914 %
VISION DISTANCE (smoke layer) =	230.8	7.7 m	2.3
SMOKE GASES : OXYGEN =	17.9 %	CO = 0.0828	CO2 = 2.1641 %
VISION DISTANCE (smoke layer) =	297.7	6.6 m	2.0
SMOKE GASES : OXYGEN =	15.8 %	CO = 0.2659	CO2 = 3.5980 %
VISION DISTANCE (smoke layer) =	260.9	6.4 m	2.0
SMOKE GASES : OXYGEN =	14.3 %	CO = 0.3520	CO2 = 4.6325 %
VISION DISTANCE (smoke layer) =	258.3	6.0 m	1.8
SMOKE GASES : OXYGEN =	13.6 %	CO = 0.4140	CO2 = 5.1313 %
VISION DISTANCE (smoke layer) =	258.3	5.7 m	1.7
SMOKE GASES : OXYGEN =	12.9 %	CO = 0.4767	CO2 = 5.5723 %
VISION DISTANCE (smoke layer) =	260.1	5.3 m	1.6
SMOKE GASES : OXYGEN =	12.3 %	CO = 0.5402	CO2 = 5.9744 %
VISION DISTANCE (smoke layer) =	263.4	5.0 m	1.5
SMOKE GASES : OXYGEN =	11.7 %	CO = 0.6043	CO2 = 6.3494 %
VISION DISTANCE (smoke layer) =	267.7	4.7 m	1.4
SMOKE GASES : OXYGEN =	11.1 %	CO = 0.6693	CO2 = 6.7052 %

VISION DISTANCE (smoke layer) =	10.6 %	CO = 0.7352	CO2 = 7.0470 %
SMOKE GASES : OXYGEN =	10.0 %	CO = 0.8022	CO2 = 7.3783 %
VISION DISTANCE (smoke layer) =	285.5	4.0 m	1.2
SMOKE GASES : OXYGEN =	9.5 %	CO = 0.8705	CO2 = 7.7019 %
VISION DISTANCE (smoke layer) =	292.6	3.7 m	1.1
SMOKE GASES : OXYGEN =	9.0 %	CO = 0.9400	CO2 = 8.0196 %
VISION DISTANCE (smoke layer) =	300.5	3.5 m	1.1
SMOKE GASES : OXYGEN =	8.5 %	CO = 1.0110	CO2 = 8.3328 %
VISION DISTANCE (smoke layer) =	321.6	3.1 m	1.0
SMOKE GASES : OXYGEN =	8.2 %	CO = 1.0828	CO2 = 8.4465 %
VISION DISTANCE (smoke layer) =	343.3	2.8 m	0.8
SMOKE GASES : OXYGEN =	8.0 %	CO = 1.1548	CO2 = 8.5828 %
VISION DISTANCE (smoke layer) =	365.6	2.4 m	0.7
SMOKE GASES : OXYGEN =	7.7 %	CO = 1.2276	CO2 = 8.7376 %

AT 759 SEC. THE OXYGEN LEVEL HAS DROPPED BELOW THAT NEEDED FOR COMBUSTION. AS LONG AS THIS CONDITION EXISTS THE CALCULATION ASSUMES THERE IS NO EFFECTIVE BURNING IN THE SMOKE LAYER. THE ENERGY RELEASE RATE WITHIN THE ROOM WILL BE LIMITED TO A VALUE BASED ON THE SPECIFIED RATE OF HEAT RELEASE, THE HEAT RELEASE RATE POSSIBLE FROM THE AIR ENTRAINMENT BELOW THE SMOKE INTERFACE, OR (IF THE VENTILATION LIMIT HAS BEEN REACHED) THE HEAT RELEASE RATE ATTAINABLE FROM THE AIR INDUCED THROUGH THE ROOM OPENINGS. WHERE THE SPECIFIED RATE OF HEAT RELEASE EXCEEDS THE RATE USED, THE EXCESS IS CONSIDERED UNBURNED FUEL IN THE SMOKE AND GASES.

VISION DISTANCE (smoke layer) =	2.3	0.7 m	5183.9	4916.9
SMOKE GASES : OXYGEN =	7.6 %	CO = 1.2496	CO2 = 8.7870 %	
INSIDE FLOW OF UNBURNED FUEL POTENTIAL	0 BTU/SEC			0 KW
TOTAL ACCUMULATION	0 BTU			0 KW
VISION DISTANCE (smoke layer) =	2.7	0.8 m	5068.8	4807.7
SMOKE GASES : OXYGEN =	6.5 %	CO = 1.3014	CO2 = 9.4331 %	
INSIDE FLOW OF UNBURNED FUEL POTENTIAL	46 BTU/SEC			49 KW
TOTAL ACCUMULATION	572 BTU			603 KW
VISION DISTANCE (smoke layer) =	3.5	1.1 m	4720.0	4476.9
SMOKE GASES : OXYGEN =	4.1 %	CO = 1.3776	CO2 = 11.2075 %	
INSIDE FLOW OF UNBURNED FUEL POTENTIAL	46 BTU/SEC			49 KW

TOTAL ACCUMULATION		1,967 BTU	2,073 KJ
840.0	449.6	232.0	3.9
VISION DISTANCE (smoke layer) =		1.2	4371.3
SMOKE GASES : OXYGEN =		0.35 m	1.15 ft
SMOKE GASES : OXYGEN =		2.3 % : CO =	1.4509 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	12.4648 %
TOTAL ACCUMULATION		3,361 BTU	49 KW
TOTAL ACCUMULATION		3,361 BTU	49 KW
870.0	402.7	205.9	4.1
VISION DISTANCE (smoke layer) =		0.33 m	1.07 ft
SMOKE GASES : OXYGEN =		1.0 % : CO =	1.5172 : CO2 =
SMOKE GASES : OXYGEN =		1.0 % : CO =	1.5172 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	13.3783 %
TOTAL ACCUMULATION		4,756 BTU	49 KW
TOTAL ACCUMULATION		4,756 BTU	49 KW
900.0	368.3	186.9	4.2
VISION DISTANCE (smoke layer) =		0.31 m	1.01 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.5745 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.5745 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	14.0744 %
TOTAL ACCUMULATION		6,150 BTU	49 KW
TOTAL ACCUMULATION		6,150 BTU	49 KW
930.0	340.7	171.5	4.3
VISION DISTANCE (smoke layer) =		0.30 m	0.97 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.6216 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.6216 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	14.0666 %
TOTAL ACCUMULATION		7,545 BTU	49 KW
TOTAL ACCUMULATION		7,545 BTU	49 KW
960.0	316.7	158.2	4.3
VISION DISTANCE (smoke layer) =		0.29 m	0.94 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.6583 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.6583 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	14.0299 %
TOTAL ACCUMULATION		8,939 BTU	49 KW
TOTAL ACCUMULATION		8,939 BTU	49 KW
990.0	294.8	146.0	4.4
VISION DISTANCE (smoke layer) =		0.28 m	0.91 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.6861 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.6861 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	14.0021 %
TOTAL ACCUMULATION		10,334 BTU	49 KW
TOTAL ACCUMULATION		10,334 BTU	49 KW
1020.0	273.9	134.4	4.4
VISION DISTANCE (smoke layer) =		0.27 m	0.88 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7065 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7065 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	13.9818 %
TOTAL ACCUMULATION		11,728 BTU	49 KW
TOTAL ACCUMULATION		11,728 BTU	49 KW
1050.0	253.6	123.1	4.5
VISION DISTANCE (smoke layer) =		0.26 m	0.86 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7206 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7206 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	13.9676 %
TOTAL ACCUMULATION		13,123 BTU	49 KW
TOTAL ACCUMULATION		13,123 BTU	49 KW
1080.0	233.5	112.0	4.6
VISION DISTANCE (smoke layer) =		0.26 m	0.84 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7298 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7298 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	13.9584 %
TOTAL ACCUMULATION		14,518 BTU	49 KW
TOTAL ACCUMULATION		14,518 BTU	49 KW
1110.0	213.5	100.8	4.6
VISION DISTANCE (smoke layer) =		0.25 m	0.82 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7351 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7351 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	13.9531 %
TOTAL ACCUMULATION		15,301 BTU	49 KW
TOTAL ACCUMULATION		15,301 BTU	49 KW

TOTAL ACCUMULATION		15,912 BTU	16,771 KJ
1131.0	200.1	93.4	4.7
VISION DISTANCE (smoke layer) =		0.25 m	0.81 ft
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7371 : CO2 =
SMOKE GASES : OXYGEN =		0.0 % : CO =	1.7371 : CO2 =
INSIDE FLOW OF UNBURNED FUEL POTENTIAL		46 BTU/SEC	13.9511 %
TOTAL ACCUMULATION		16,842 BTU	49 KW
TOTAL ACCUMULATION		16,842 BTU	49 KW

ASCII FILE NAME: CON-MIX1.PRN

HEAT OF COMBUSTION: 8607.33 BTU/lb 20000.00 KJ/Kg
 SPECIFIC EXTINCTION COEFFICIENT: .10
 FLASHOVER TEMPERATURE: 1112.00 F 600.00 C
 OXYGEN STARVATION THRESHOLD: 10.00 % BY VOLUME
 RADIANT ENERGY FRACTION (FROM FLAME): .35
 MAXIMUM PRE FLASHOVER ENERGY LOSS: .96

SPRINKLER/HEAT DETECTOR DESCRIPTION:
 RADIAL DISTANCE 7.00 ft 2.13 m
 RTI: 50.00 (Ft-Sec)^{1/2} 27.60 (m-Sec)^{1/2}
 SPRINKLER RATING: 160.00 F 71.11 C
 SPRINKLER IS NOT SIDEWALL MOUNTED

SMOKE DETECTOR DESCRIPTION:
 SMOKE TEMPERATURE AT DETECTION: 93 F 33.88889 C
 SMOKE DETECTOR IS NOT SIDEWALL MOUNTED

DESCRIPTION OF INITIAL OUTSIDE OPENING:
 HEIGHT OF OPENING: 6.60 ft 2.01 m
 WIDTH OF OPENING: 3.00 ft 0.91 m
 HEIGHT OF SILL ABOVE FLOOR: 0.00 ft 0.00 m

SPACIAL DIMENSIONS OF ROOM:
 ROOM HEIGHT: 8.50 ft 2.59 m
 ROOM FLOOR AREA: 299.99 ft² 27.87 m²
 ROOM WALL PERIMETER: 74.00 ft 22.56 m
 ROOM IS RECTANGULAR: 25.00 ft BY 12.00 ft 7.62 m BY 3.66 m

DESCRIPTION OF CEILING MATERIALS:
 100 % MINERAL CEILING 1 IN 25.4 mm
 DESCRIPTION OF WALL MATERIALS:
 100 % GYPSUM BOARD .5 IN 12.7 mm

THERE IS NO HVAC DEFINED

FIRE HEIGHT: 0.00 ft 0.00 m

FAST EXP. TO 1M THEN FAST T-SQ. TO 8MW 1 MIN STEADY THEN DECAY TO 0
 FIRE DESCRIPTION USED CAME FROM FILEFILE: COE-8EX.FIR 4-14-1990

A HALT FLAG IS SET FOR TIME = 330 Sec

TIME	-----TEMP-----	-----LAYER-----	-----FIRE-----
sec	F C	ft m	kW BTU/sec
0.0	70.0 21.1	8.5 2.6	0.1 0.1
SMOKE AT SMOKE DETECTOR = 0 % OF DETECTABLE CONCENTRATION			
LINK TEMPERATURE	= 70.0 F 21.1 C		

APPENDIX D

Printout of results of FIRE SIMULATOR runs used to estimate the response of sprinklers and smoke detectors.

INPUT DATA USED FOR RUN OF: 11-05-1990 08:21:07

DATA FILE USED: CON-MIX1.IN AS OF 11/05/90 08:20:12

TITLE: 20 MASS CONFERENCE ROOM PRIOR TO CEILING FAILURE 04-10-1990

ASCII FILE NAME: CON-MIX1.PRN

HEAT OF COMBUSTION: 8607.33 BTU/lb 20000.00 KJ/Kg

SPECIFIC EXTINCTION COEFFICIENT: .10 600.00 C

FLASHOVER TEMPERATURE: 1112.00 F

OXYGEN STARVATION THRESHOLD: 10.00 % by VOLUME

RADIANT ENERGY FRACTION (FROM FLAME): .35

MAXIMUM PRE FLASHOVER ENERGY LOSS: .96

SPRINKLER/HEAT DETECTOR DESCRIPTION: 2.13 m

RADIAL DISTANCE: 7.00 ft

RTI: 300.00 (Ft-Sec)^{1.5} 165.63 (m-Sec)^{1.5}

SPRINKLER RATING: 165.00 F 73.89 C

SPRINKLER IS NOT SIDEWALL MOUNTED

THERE IS NO SMOKE DETECTOR DEFINED

DESCRIPTION OF INITIAL OUTSIDE OPENING: 6.60 ft 2.01 m

HEIGHT OF OPENING: 3.00 ft 0.91 m

HEIGHT OF STILL ABOVE FLOOR: 0.00 ft 0.00 m

SPECIAL DIMENSIONS OF ROOM: 8.50 ft 2.59 m

ROOM HEIGHT: 299.99 ft² 27.87 m²

ROOM FLOOR AREA: 74.00 ft 22.56 m

ROOM WALL PERIMETER: 25.00 ft 12.00 ft 7.62 m 3.66 m

ROOM IS RECTANGULAR: BY

DESCRIPTION OF CEILING MATERIALS: 1 IN 25.4 mm

100 % MINERAL CEILING

DESCRIPTION OF WALL MATERIALS: 12.7 mm

100 % GYPSUM BOARD

THERE IS NO HVAC DEFINED

FIRE HEIGHT: 0.00 ft 0.00 m

FAST EXP. TO 1M THEN FAST T-SQ. TO 8MW 1 MIN STEADY THEN DECAY TO 0

FIRE DESCRIPTION USED CAME FROM FILE: COE-8EX.FIR 4-14-1990

HALT FLAG IS SET FOR TIME = 330 Sec

TIME	TEMP	LAYER	FIRE
sec	F	C	ft
0.0	76.0	21.1	8.5
LINK TEMPERATURE	=	70.0 F	21.1 C
ceiling Jet Temperature (at link)	=	70.6 F	21.4 C
ceiling Jet Velocity (at link)	=	0.25 ft/sec	0.08 m/sec
VISION DISTANCE (smoke layer)	=	3000.00 m	9842.52 ft

ceiling Jet Temperature (at link) = 70.6 F 21.4 C
ceiling Jet Velocity (at link) = 0.25 ft/sec 0.08 m/sec
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft
SMOKE GASES : OXYGEN = 21.0 % : CO = 0.0000 : CO2 = 0.0000 %
SMOKE VENT RATE IS 0 cfm 0.00 cms
ENTHALPY (Heat content) 0 btu/sec 0 kW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 kW

SMOKE DETECTOR ACTIVATED AT 82 SECONDS

82.0 92.5 33.6 5.1 1.6 45.2 42.9
LINK TEMPERATURE = 84.0 F 28.9 C
ceiling Jet Temperature (at link) = 102.5 F 39.2 C
ceiling Jet Velocity (at link) = 1.93 ft/sec 0.59 m/sec
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft
SMOKE GASES : OXYGEN = 20.8 % : CO = 0.0000 : CO2 = 0.1429 %
SMOKE VENT RATE IS 228 cfm 0.11 cms
ENTHALPY (Heat content) 1 btu/sec 2 kW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 kW

SPRINKLER/HEAT DETECTOR ACTIVATED AT 133 SECONDS

133.0 241.5 116.4 3.5 1.1 481.8 457.0
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft
SMOKE GASES : OXYGEN = 19.7 % : CO = 0.0000 : CO2 = 0.9502 %
SMOKE VENT RATE IS 75 cfm 0.92 cms
ENTHALPY (Heat content) 75 btu/sec 79 kW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 kW

134.0 241.5 116.4 3.5 1.1 481.8 457.0
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft
SMOKE GASES : OXYGEN = 19.7 % : CO = 0.0001 : CO2 = 0.9893 %
SMOKE VENT RATE IS 1960 cfm 0.92 cms
ENTHALPY (Heat content) 75 btu/sec 79 kW
INSIDE FLOW OF UNBURIED FUEL POTENTIAL 0 BTU/SEC 0 kW

=====RUN COMPLETED=====

SPRINKLER/HEAT DETECTOR
ACTIVATED AT 169 SECONDS

169.0	731.6	388.7	3.0	0.9	1324.7	1256.5
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft						
SMOKE GASES : OXYGEN = 15.9 % : CO = 0.0015 : CO2 = 3.7321 %						
SMOKE VENT RATE IS 4751 cfm 2.24 cms						
ENTHALPY (Heat content) 410 btu/sec 432 kW						
INSIDE FLOW OF UNBURNED FUEL POTENTIAL 0 BTU/SEC 0 kW						
170.0	731.6	388.7	3.0	0.9	1324.7	1256.5
VISION DISTANCE (smoke layer) = 3000.00 m 9842.52 ft						
SMOKE GASES : OXYGEN = 15.9 % : CO = 0.0017 : CO2 = 3.8386 %						
SMOKE VENT RATE IS 4751 cfm 2.24 cms						
ENTHALPY (Heat content) 410 btu/sec 432 kW						
INSIDE FLOW OF UNBURNED FUEL POTENTIAL 0 BTU/SEC 0 kW						

=====RUN COMPLETED=====

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ABSTRACT (A 2000-CHARACTER OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, CITE IT HERE. SPELL OUT ACRONYMS ON FIRST REFERENCE.) (CONTINUE ON SEPARATE PAGE, IF NECESSARY.) The analysis of an office building fire was made using fire modeling techniques. The data to conduct the analysis was obtained through on-site inspection and interviews. The analysis describes a rapid fire developing in easily ignited boxing materials that flashed over in about six minutes from flame initiation, causing failure of the ceiling system, venting of fire products in the plenum system above the ceiling, and rapid filling of the entire flow area with smoke. The report suggests a likely source of ignition and provides analysis of the impact that several fire protection systems would have had were they present at the time of this fire.																																					
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